21st of March 2013

DIGITAL PHOTONIC PRODUCTION

Fertigungstechnisches Seminar der ETH Zürich
"Ultrafast Lasers – Technologies and Applications"

Prof. Dr. Reinhart Poprawe, Aachen

RWTH Rheinisch-Westfälische Technische Hochschule Aachen
Lehrstuhl für Lasertechnik LLT

Fraunhofer ILT

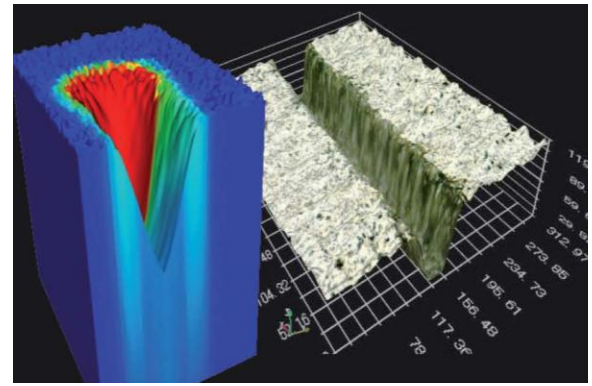
Who we are …

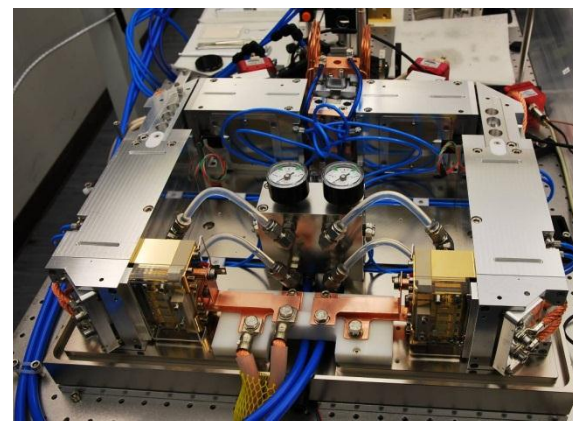
Facts and Figures of Fraunhofer ILT and RWTH Aachen University LLT, TOS, NLD

- About € 31 Mio operating budget (without investments)
- About € 4 Mio investments per year
- More than 250 current projects for industrial partners per year
- App. 400 @ ILT, 150 @ 3 RWTH-Chairs, 200 @ App-Center
- DQS certified according to DIN EN ISO 9001
- 2 branches abroad:
  - Center for Laser Technology CLT
  - Coopération Laser Franco-Allemande CLFA
- One patent application per month on average
- 30 Spin offs in the last 25 years

Outline and Questions

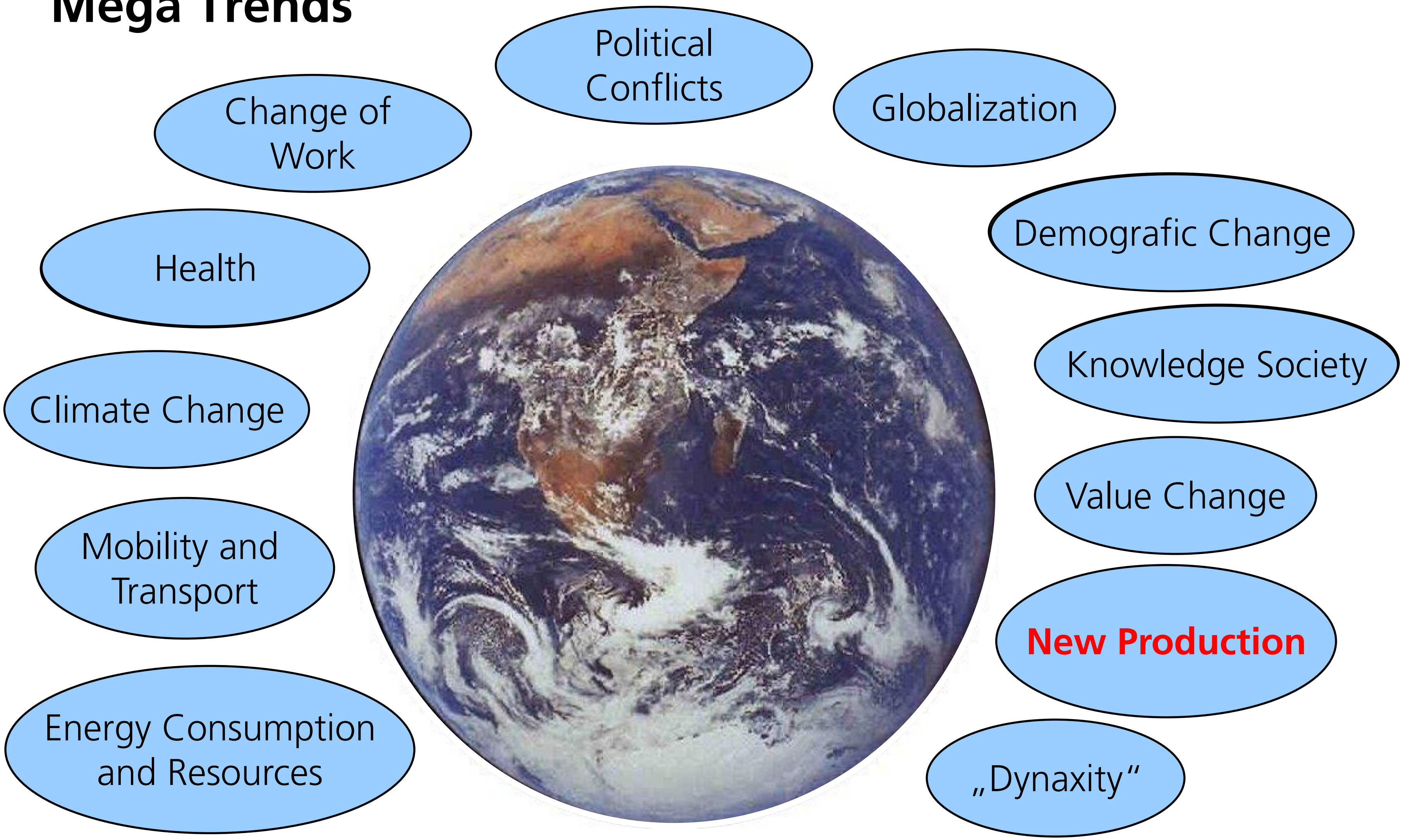
- Limits of present productions Technology: The Dilemmas
- What is Digital Photonic Production and why is it widely developing?
- 3 pictures on the fundamentals
- Applications
  - Surface
  - Volume exposure
  - Volume ablation
  - System Development
- Diode Laser Technology will decide global leadership





What we want …

Mega Trends

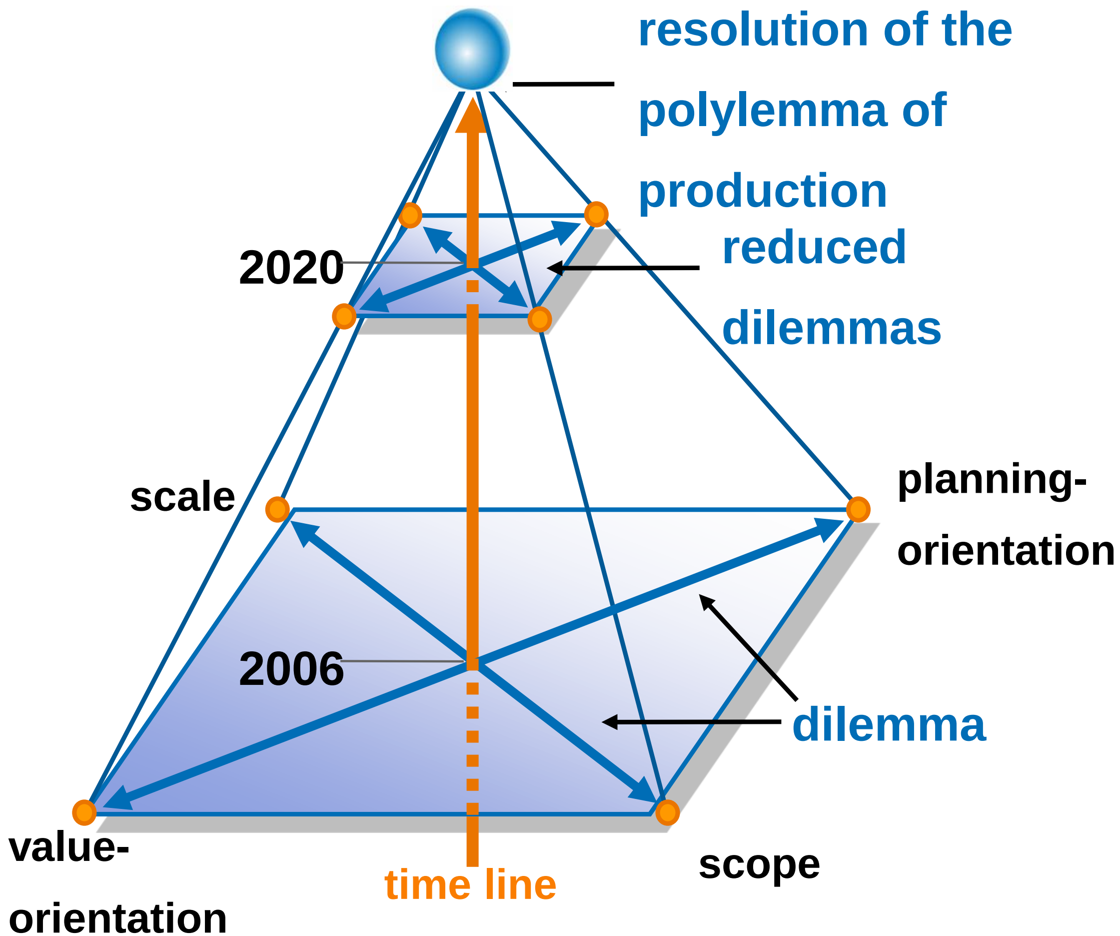


„Fraunhofer Gesellschaft Z punkt.-Lebenswelten 2015 plus“, „Siemens-Horizons 2020“

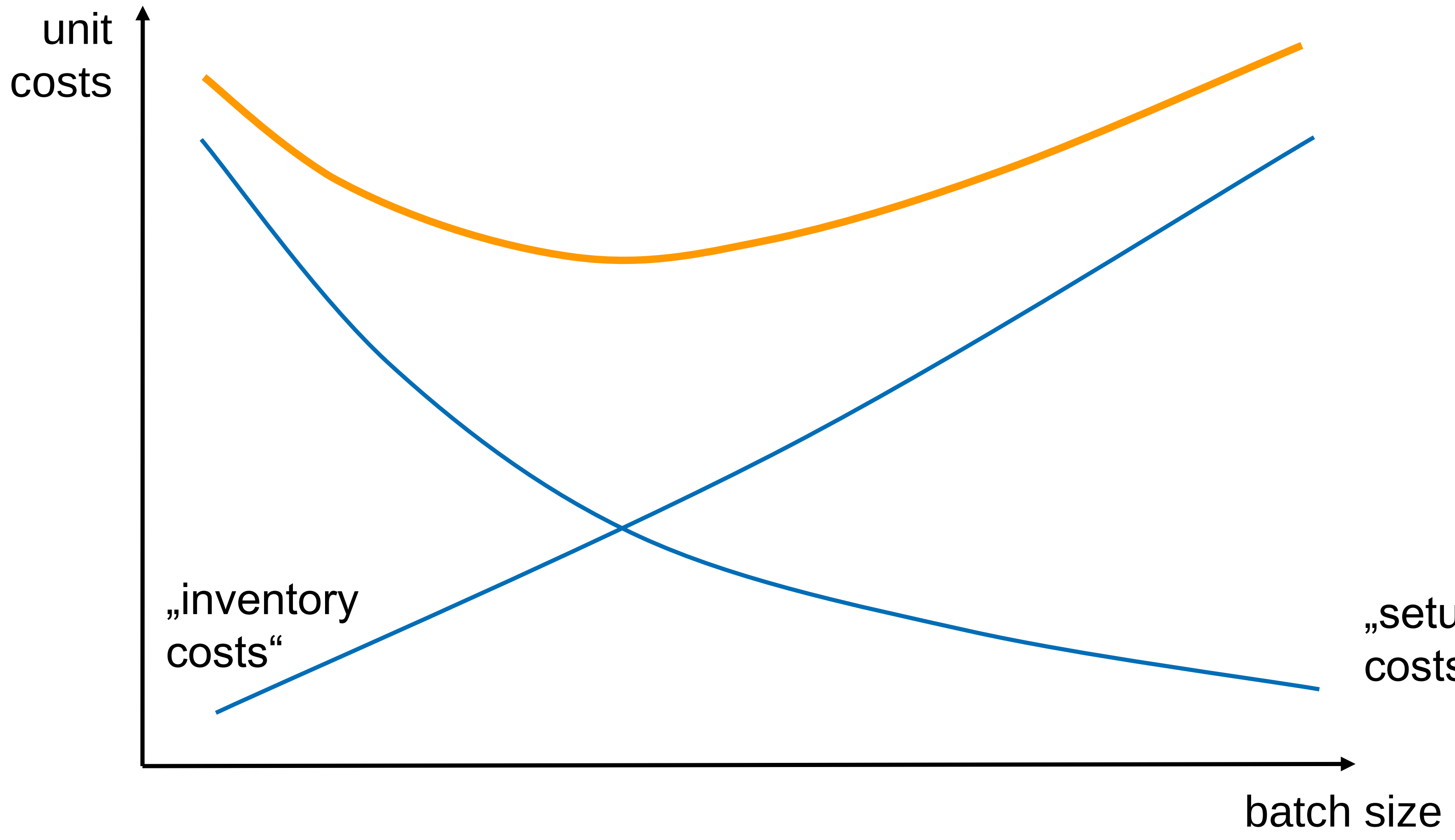
Dilemata in Present Production Technology

The Research Objective of Production Technology: Resolution of the Polylemma of Production

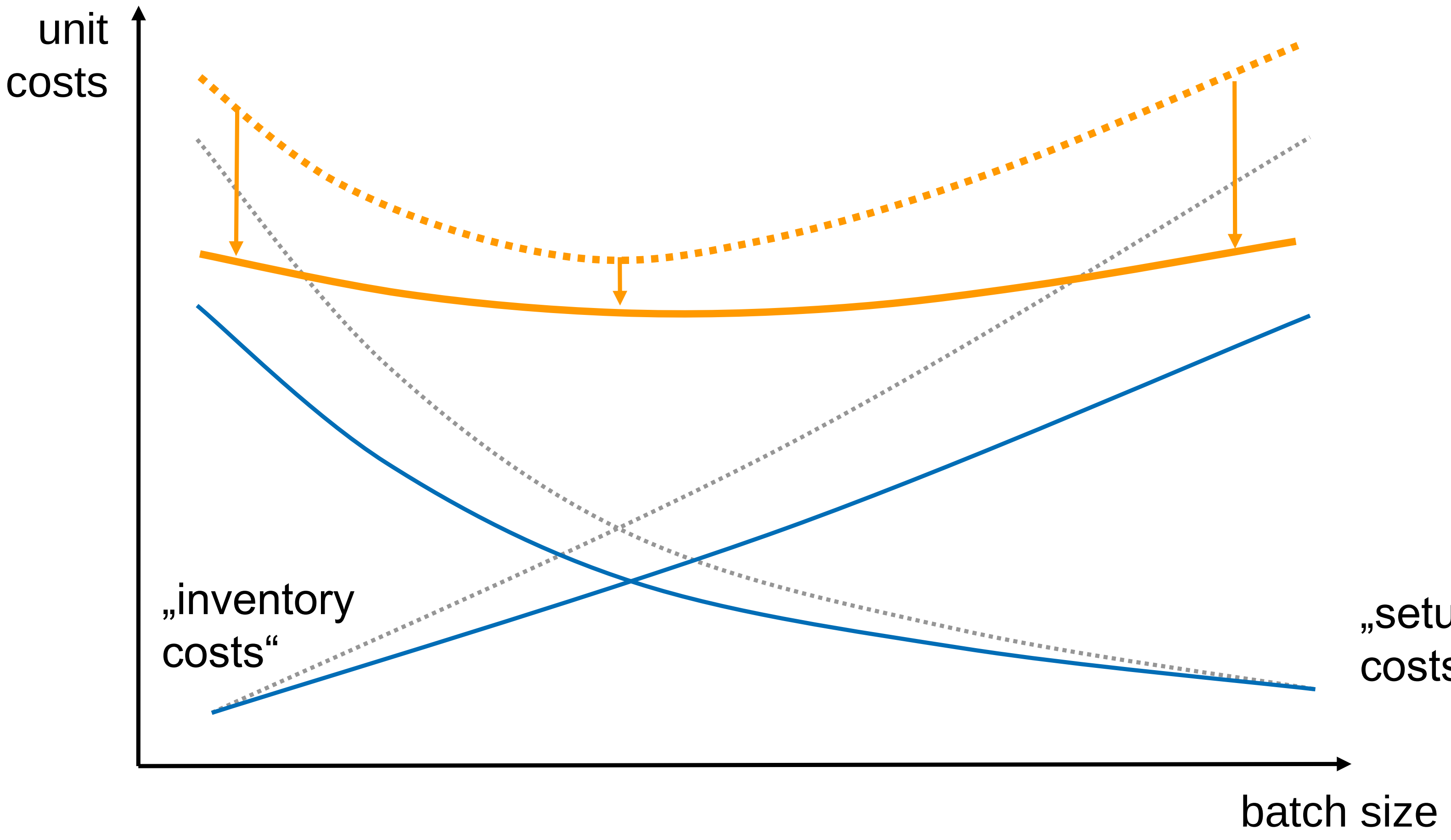
Vision of Integrative Production Technology



The Research Objective of Production Technology at the Beginning of the 21st Century



The Research Objective of Production Technology at the Beginning of the 21st Century

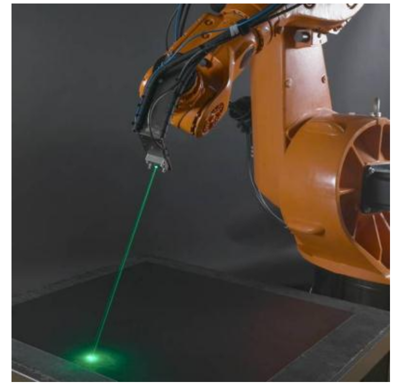


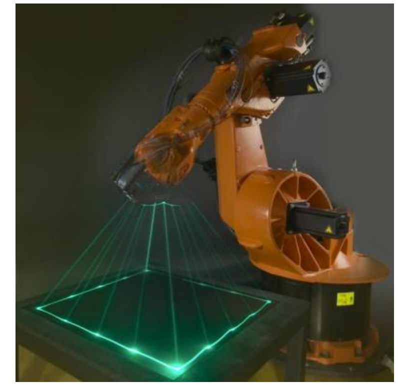
What we have …

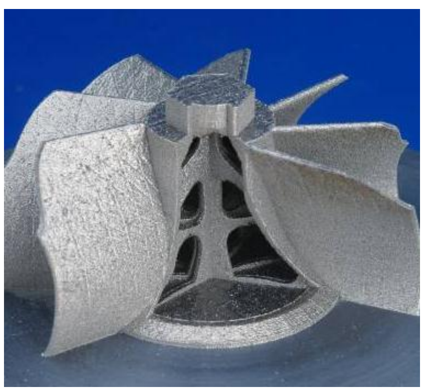
Digital Photonic Production – “Bits to Photons to Atoms”

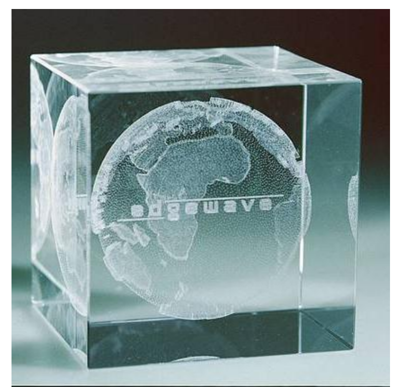
Using light as a tool means …

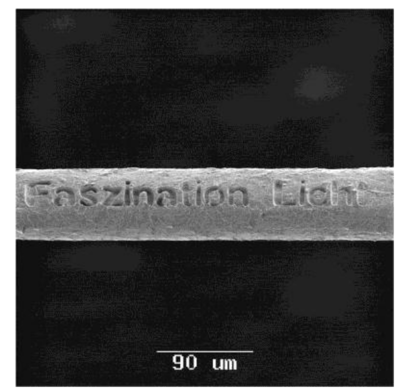
- highest power density
- highest speed
- shortest interaction (precision)
- **mass-less, force-less, no mechanical tools**
- best controllability (CAD to product)





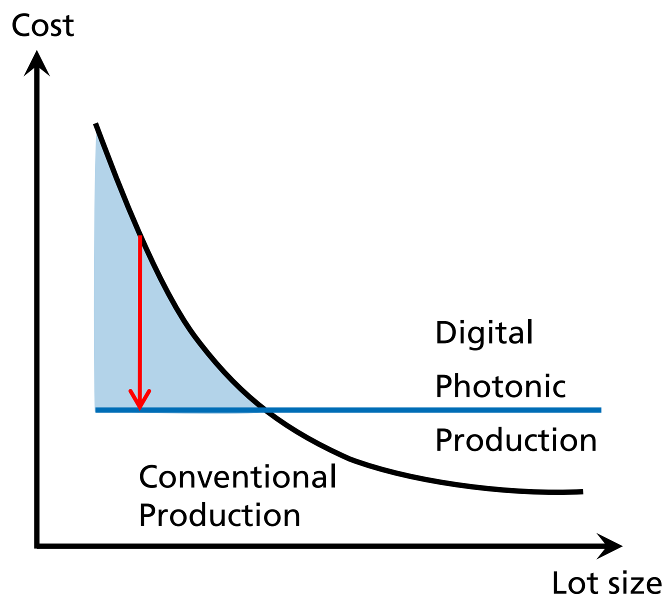


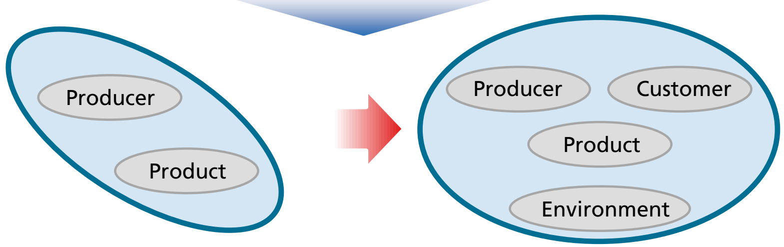




Digital Photonic Production – "Production 2.0"

Individualisation for free



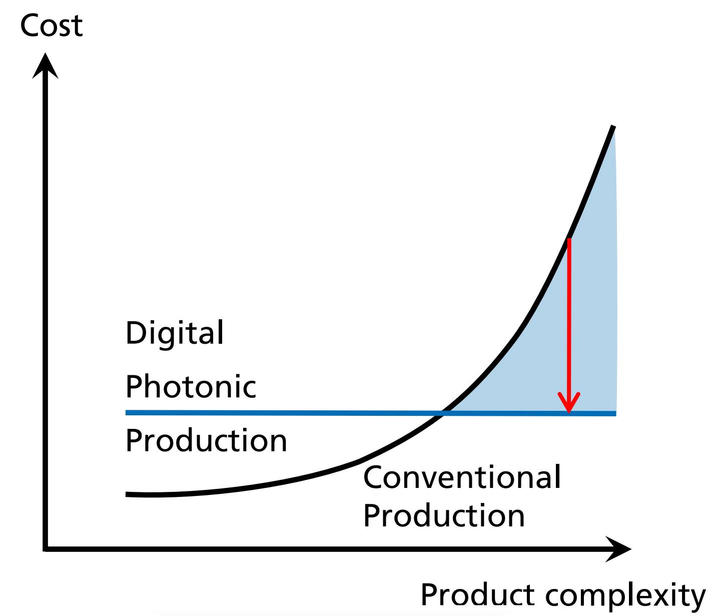


Providing-Value

Value-Co-Creation

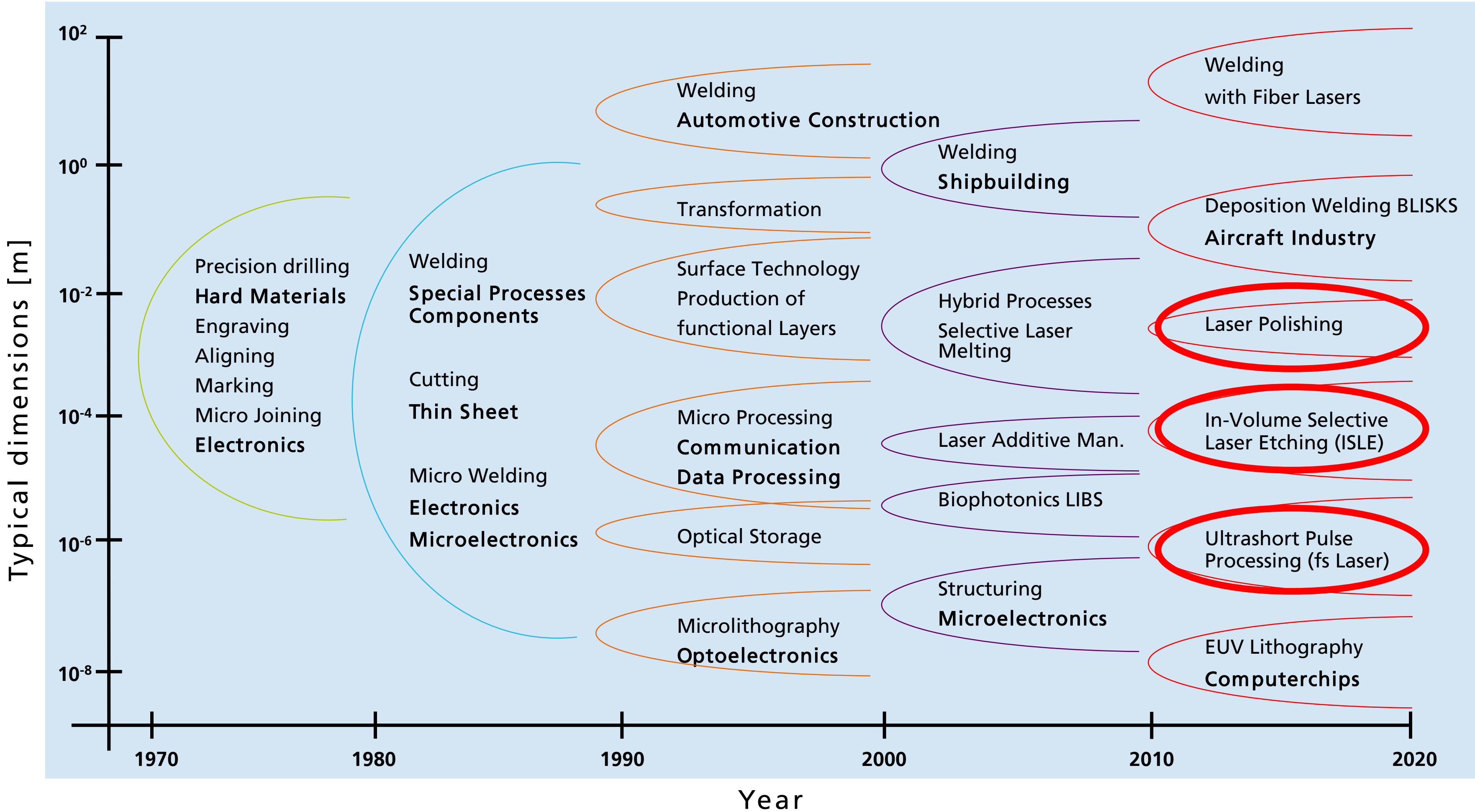
Innovative business models

Complexity for free



Innovative products

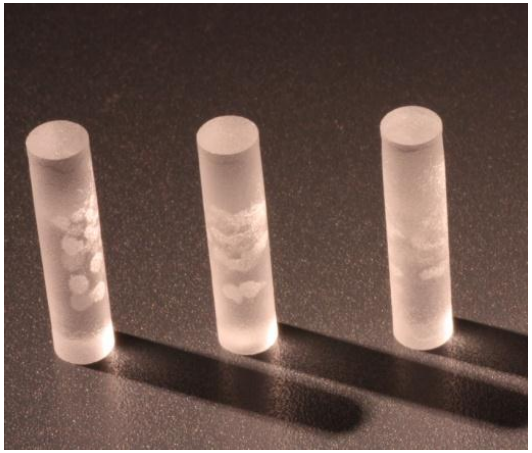
Photonic Production – Growing Fields of Application

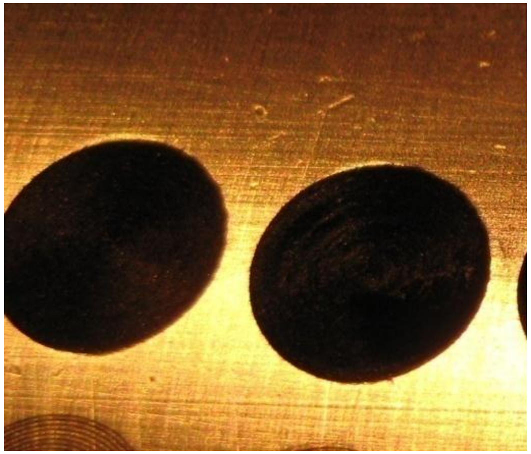
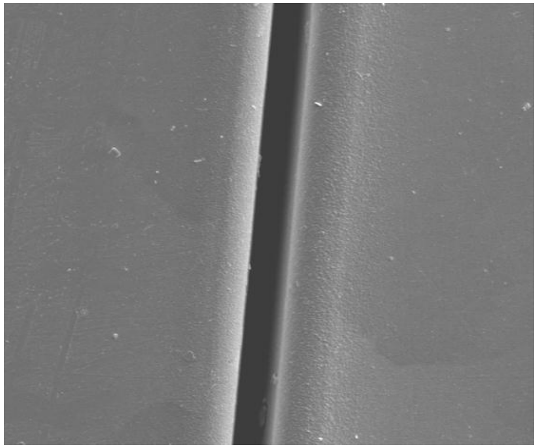
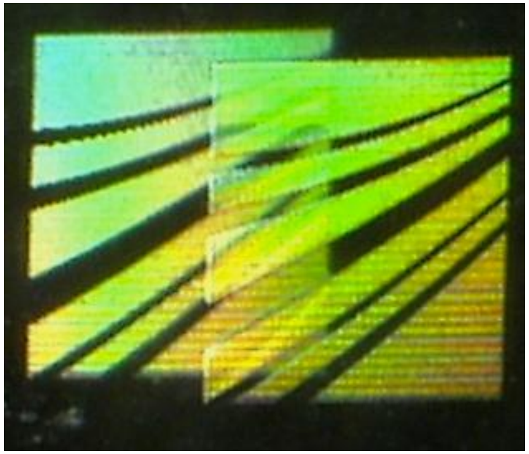
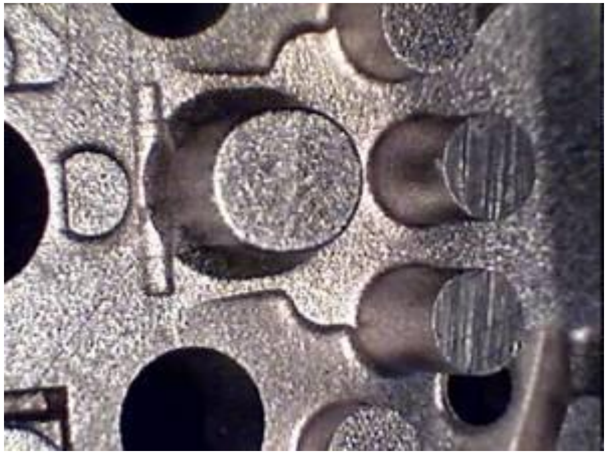


RWTH LLT RHEINISCH-WESTFÄLISCHE TECHNISCHE HOCHSCHULE AACHEN LEHRSTUHL FÜR LASERTECHNIK

Fraunhofer ILT

Ultrafast Precision Meets High Power



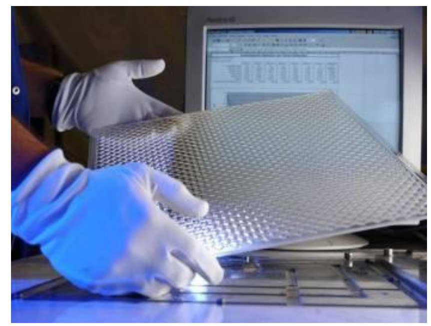





Motivation

High precision and high throughput manufacturing of various materials and products

Multi-component materials and multi-layer systems

Friction reduction and functionalized surfaces



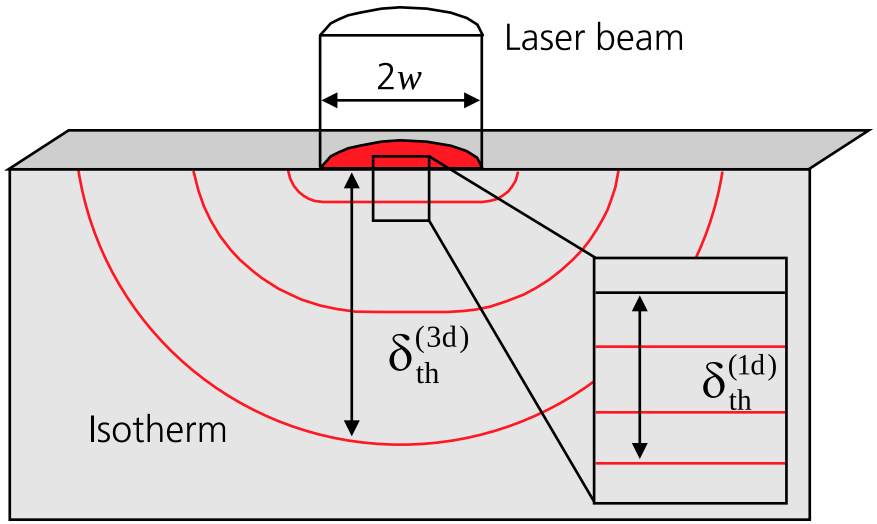
Integrated optics, semiconductor technology

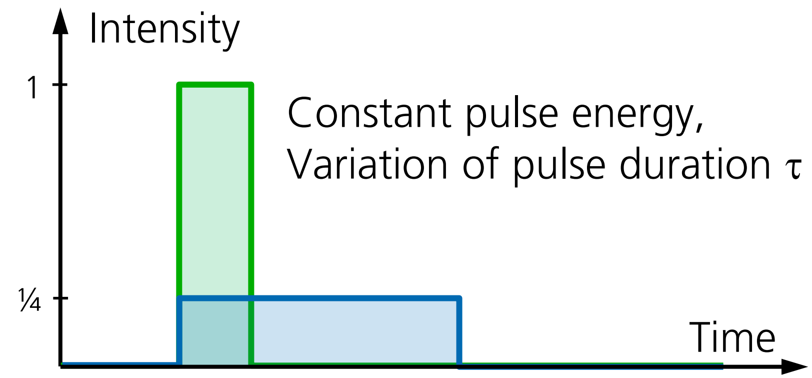
Life science and medicine technology

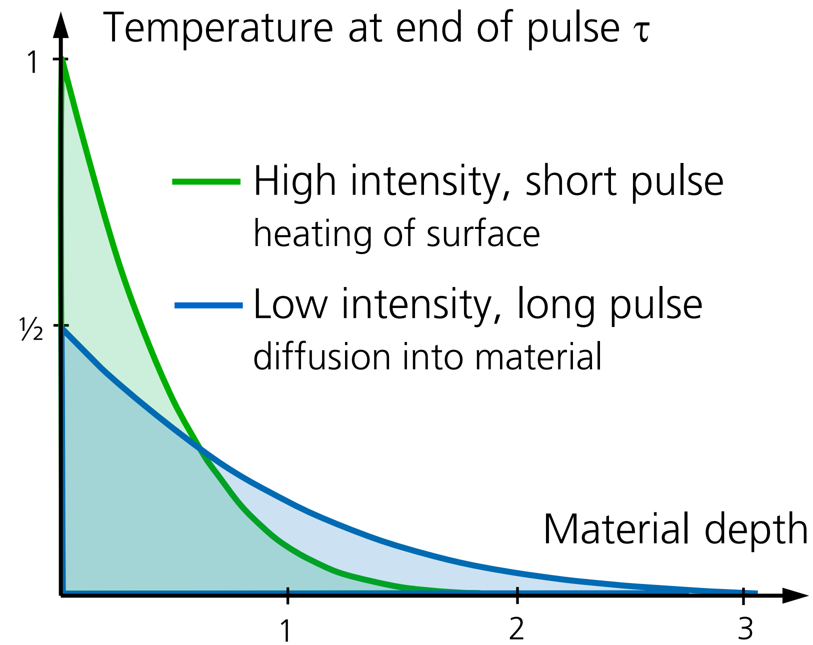
→ Ultrashort pulse laser radiation with high average power

Physical Basics

Time Scales of Thermal Processes







Solution of 1d heat conduction problem:

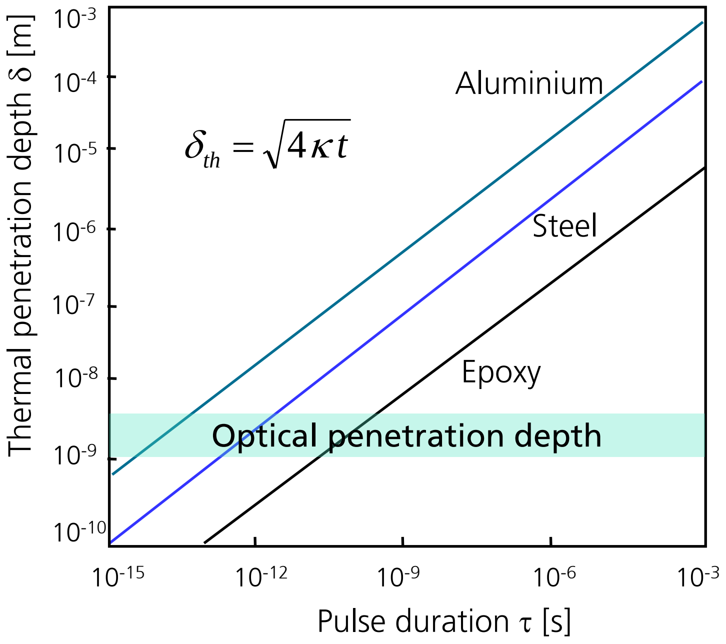
$$T(z,t) - T_0 = \frac{I_{abs}}{\sqrt{\lambda \rho c}} \sqrt{t}\; 2\, ierfc\left(\frac{z}{\delta_{th}(t)}\right)$$

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

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

Thermal Penetration Depth and Melt Film Thickness

Material	Optical penetration depth α^{-1} [mm]		
	Excimer Laser	Nd:YAG Laser	CO_2 Laser
Metal	10^{-5}	$< 10^{-5}$	10^{-6}
Glass	$> 10^{-4}$	> 100	> 0.1
Ceramic	$5\cdot10^{-5}$-0.02	> 0.001	0.001
Polymer	10^{-5}-10^{-2}	$> 10^{-5}$	10^{-3}-10^{-2}

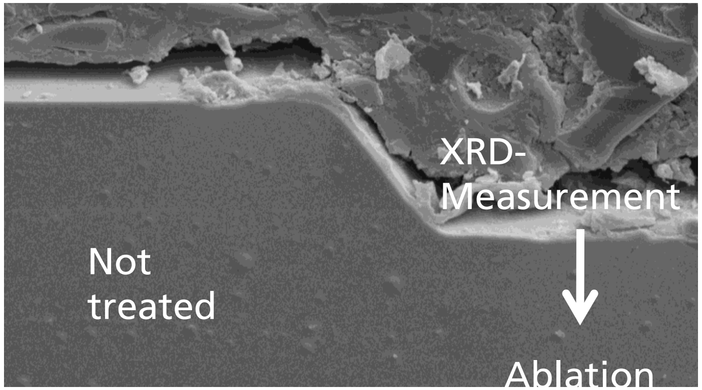


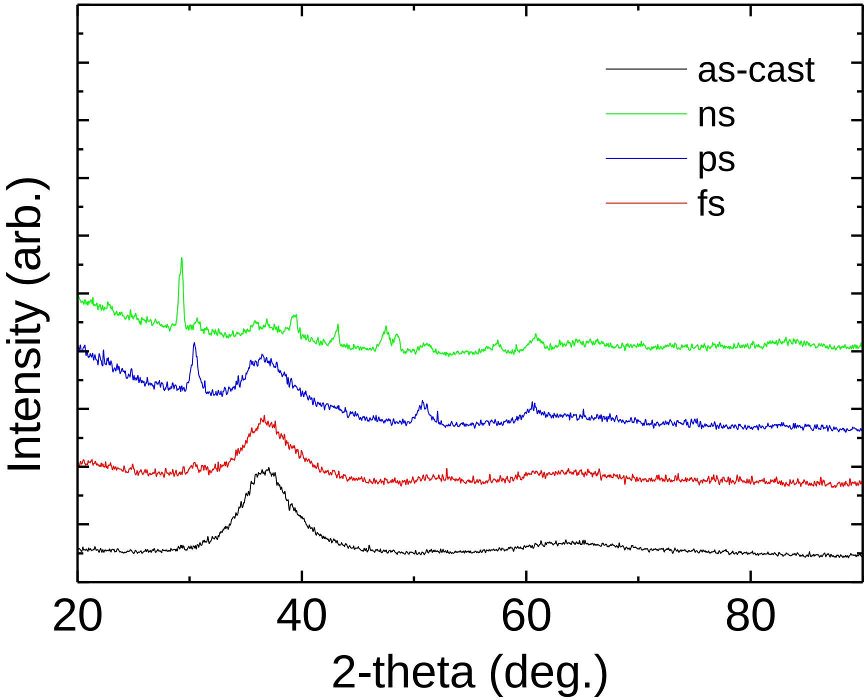
$$T(z,t) - T_0 = \frac{I_{abs}}{\sqrt{\lambda \rho c}} \sqrt{t}\; 2\, ierfc\left(\frac{z}{\delta_{th}(t)}\right)$$

Heat Diffusion

High Intensity, short pulse duration

→ Small heat affected zone, no recast



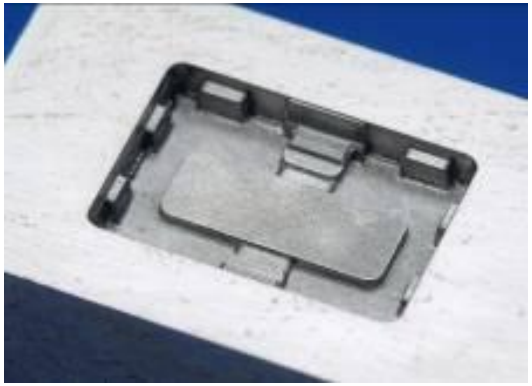


XRD-spectra at the ablation ground for different pulse durations

- Melt temperature $T_M = 265°C$
- Estimated penetration depth **below 1 µm**

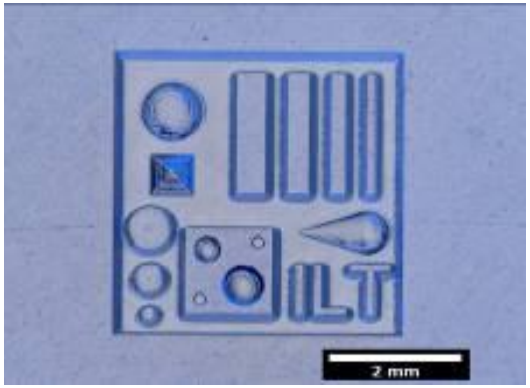
Materials

Steel



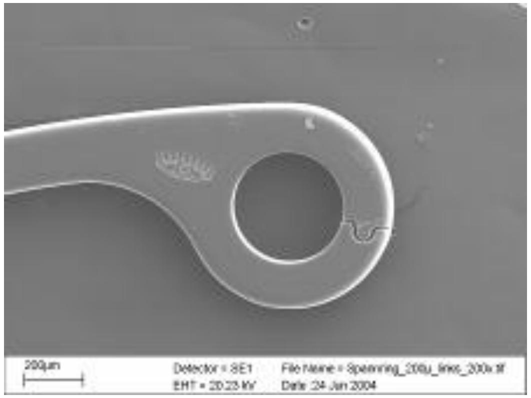
- Injection molding tools
- Forming tools
- Tribological structures

Ceramics



- Ceramic-Substrates for printed circuit boards
- Ceramic micro components
- PCD- and Sapphire-Tools

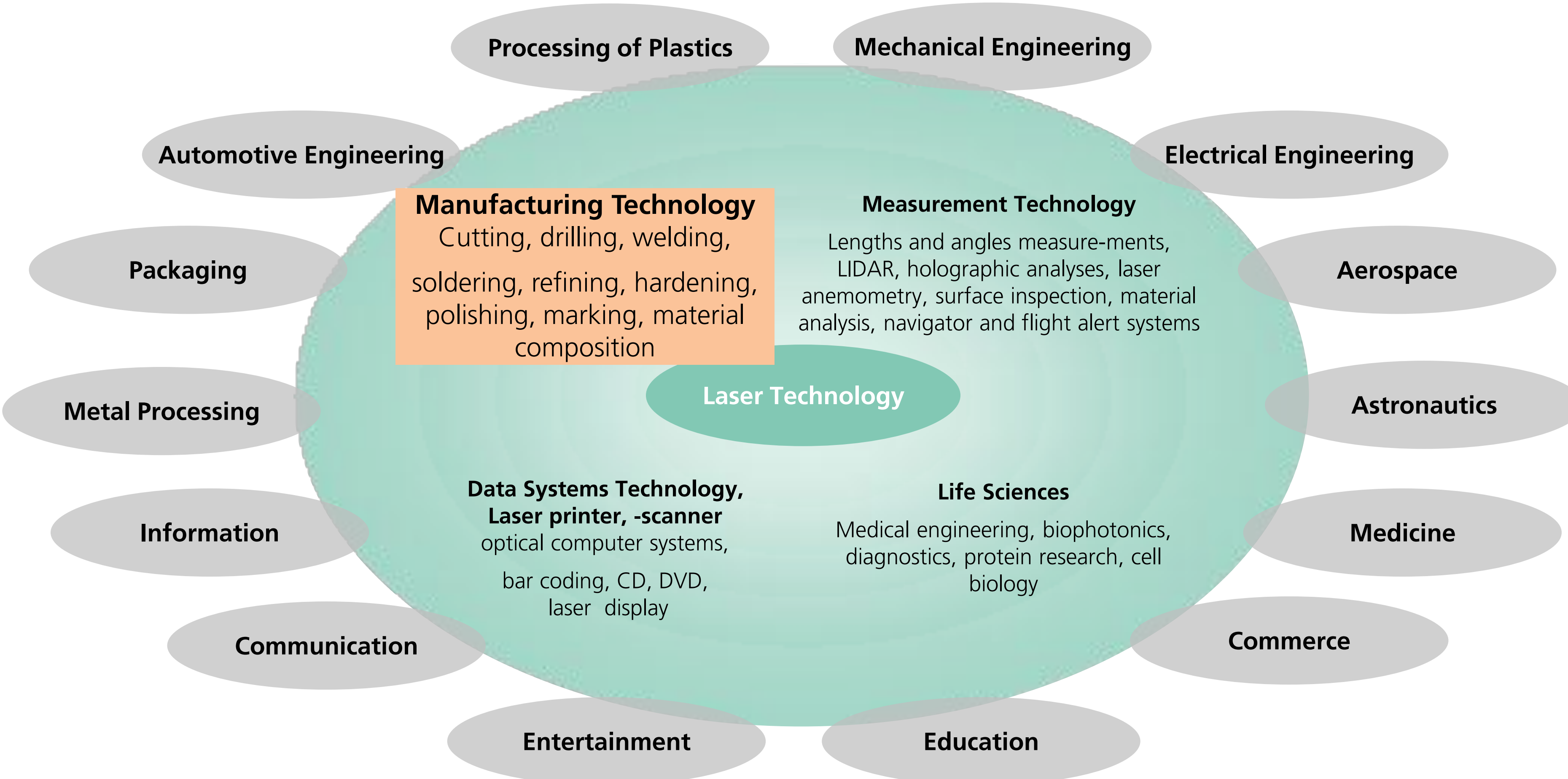
Polymers



- Medical technology
- Micro fluidics
- Micro optics

Markets and Applications

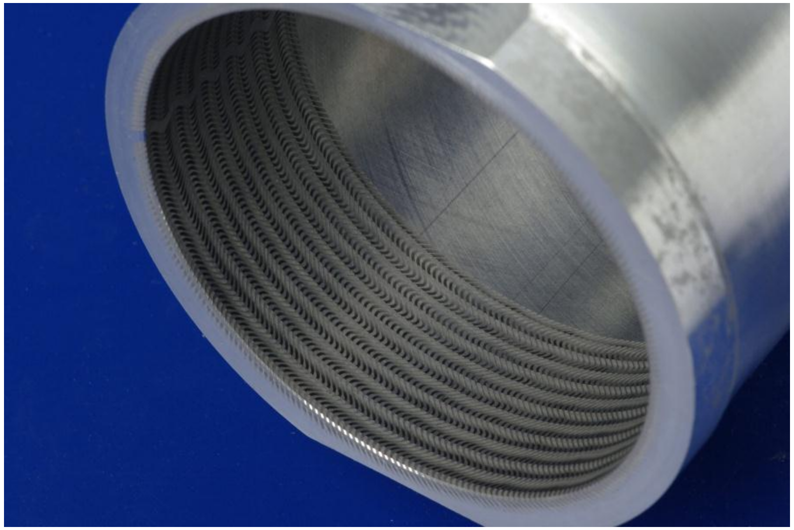
Application Markets

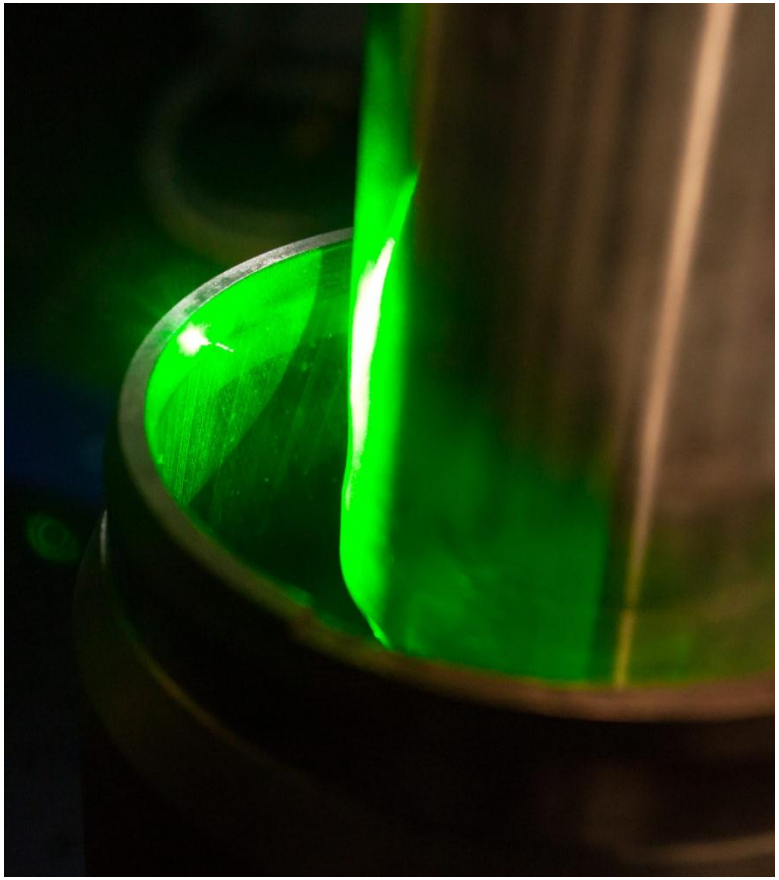


Surface Ablation by Ultrafast Lasers

Functional Surfaces
Laser Structuring of Motor Components

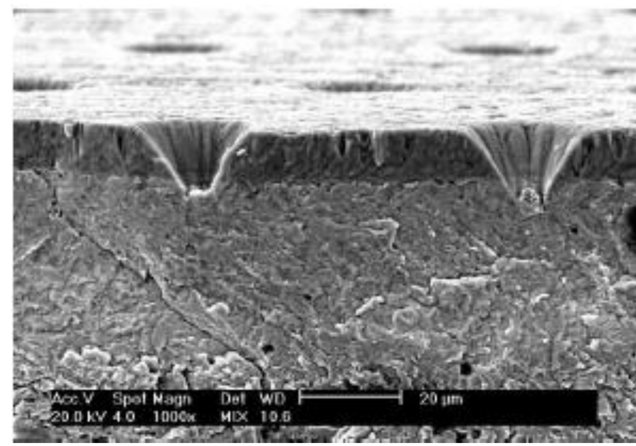
- Aim: reduction of friction and wear
- Structures act as oil reservoir and a hydrodynamic bearing
- Compromise between efficiency and oil consumption



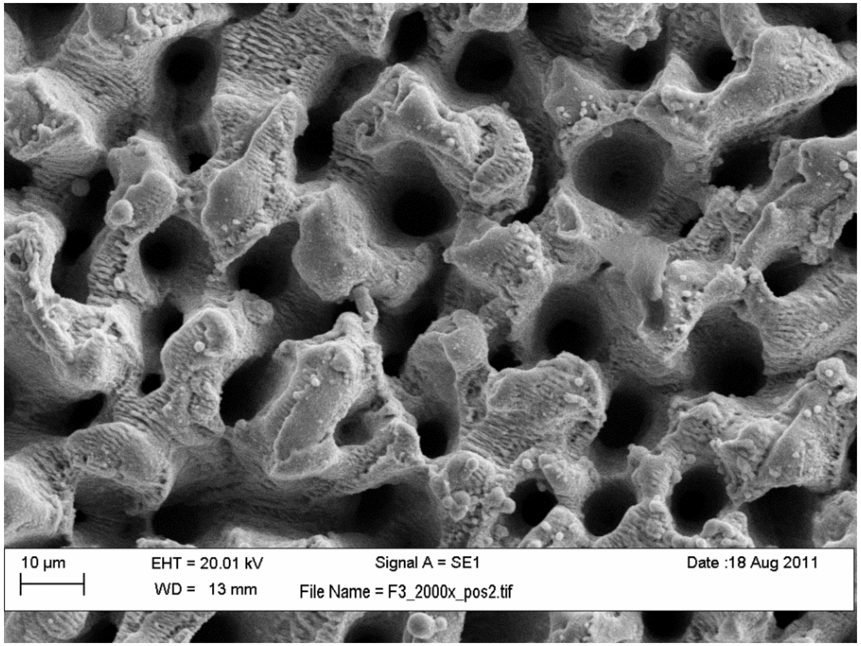


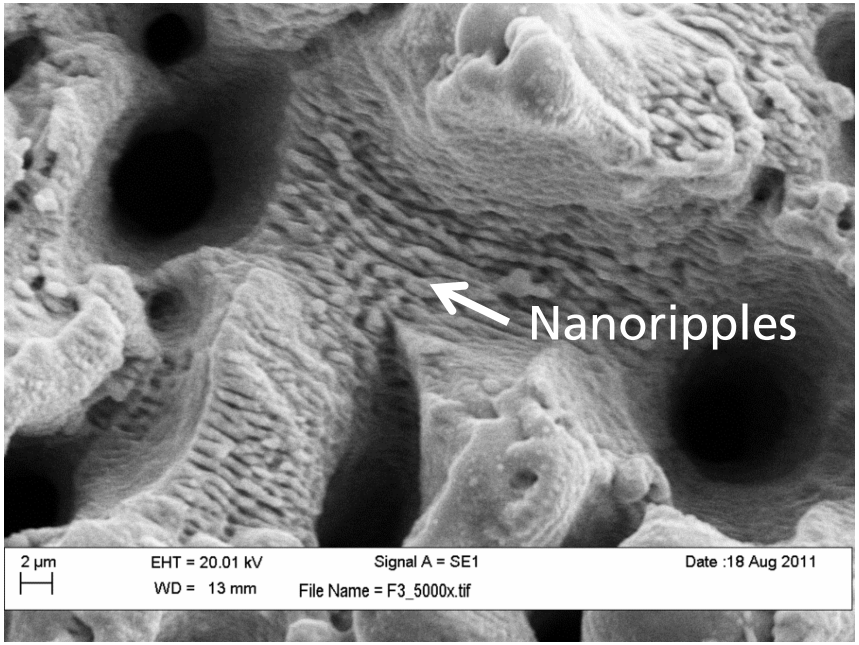
Functional Surfaces
Laser Structuring of Motor Components

- 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





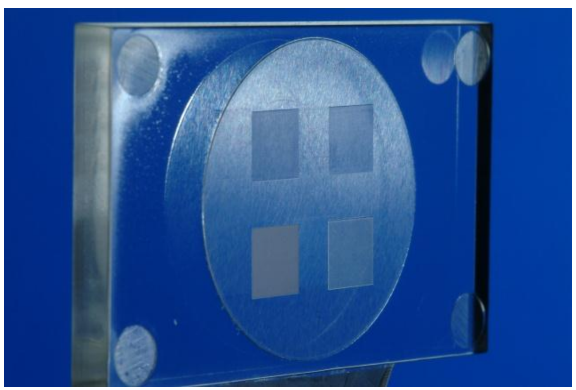
- Cone-like-protrusions (CLPs)
- Statistical structure effect that occurs by redistribution of melt during ablation with ultrashort laser pulses
- Structure sizes: 6-10µm

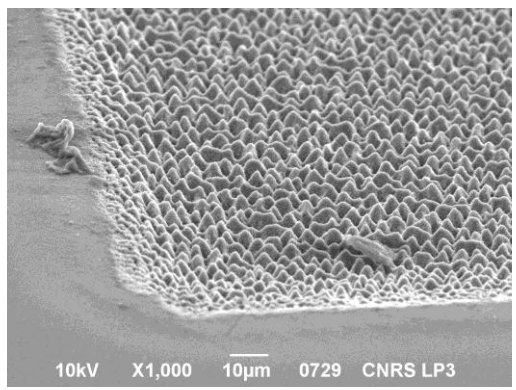
Nano ripples

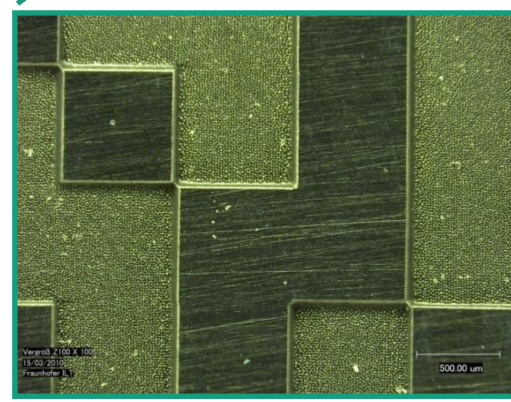
- Overlay of nanostructures
- Structure size: ~1µm

Functional Surfaces
Surface Roughening

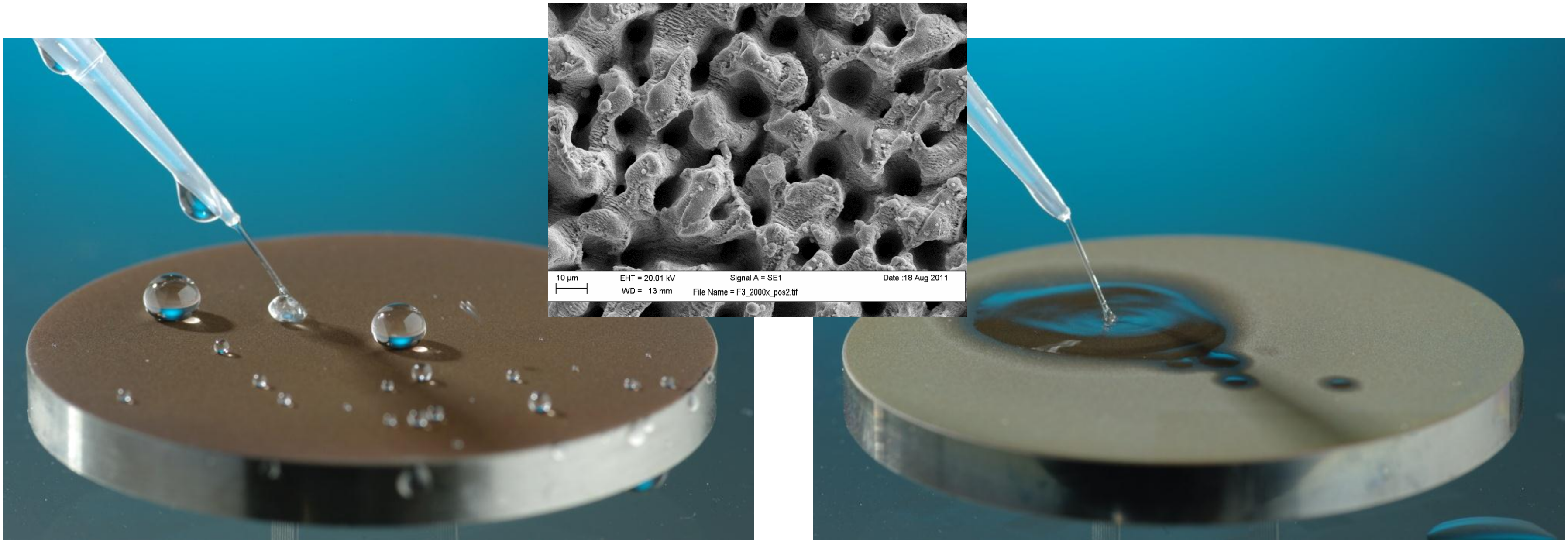
- Ablation of 10-30 layers with high laser intensity
- Generation of structures with high aspect ratio (>10)
- Applications
  - Anti-reflection surface
  - Scattering area
  - Change of wetting behaviour







Functional Surfaces
CLPs - Extreme Enhancement of the Surface Area



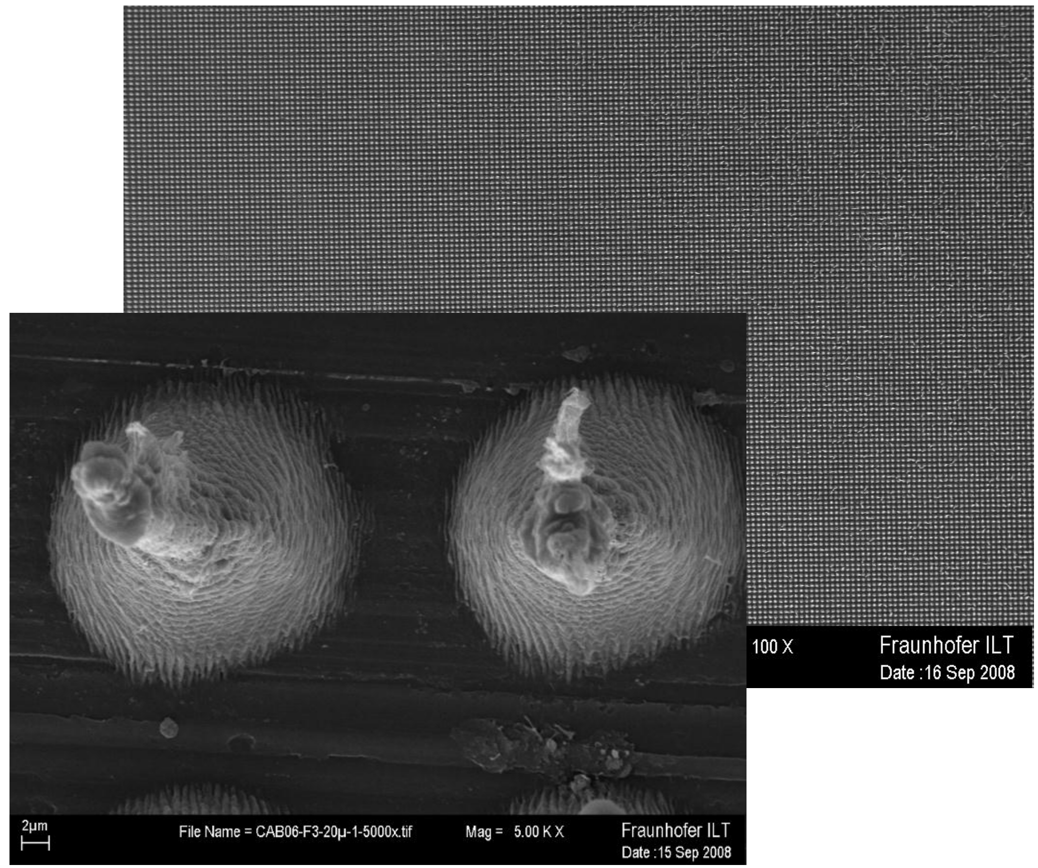
- Hydrophobic coating
  - CLP (6-7 µm)
  - HMDSO Plasma Coating (300 nm)
  - Contact angle > 150°

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

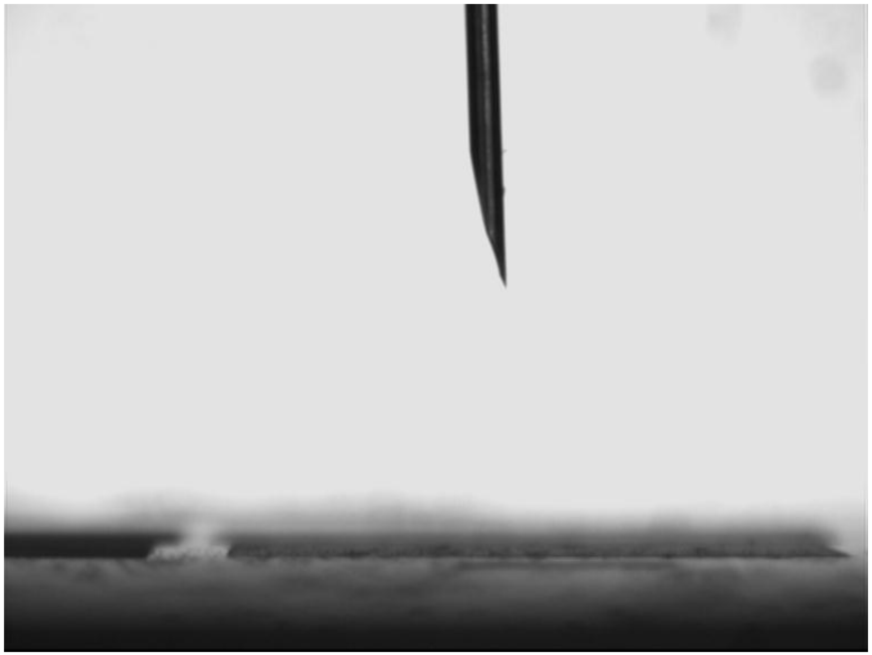
Functional Surfaces

Hydrophobic Surfaces

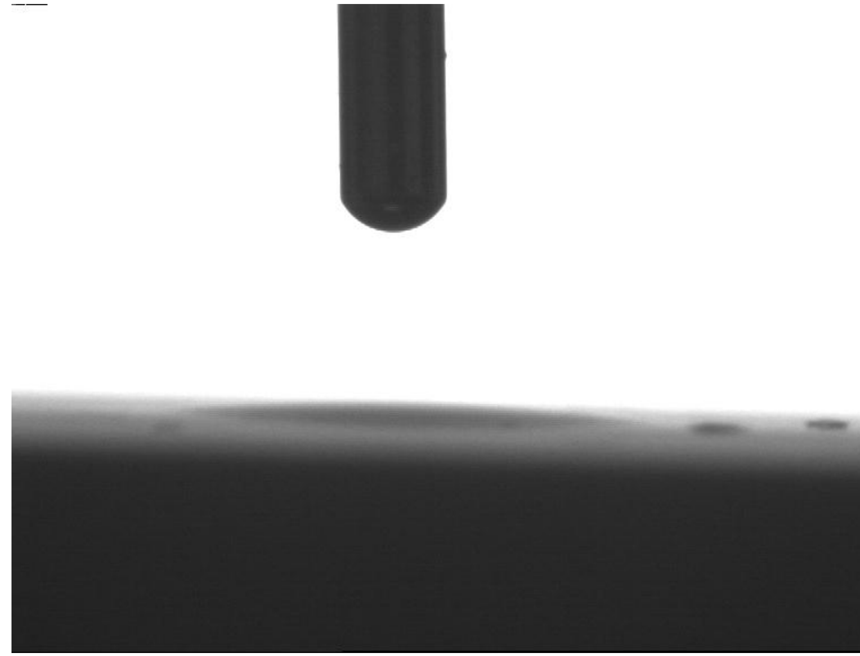
- Structuring of injection moulding tools
- Laser: Lumera Rapid (λ = 355 nm)
- Generation of multiple structures
  - Structure size: 10 µm
  - Sub-structure: 100 nm
- Material: PP, PE



Hydrophobic Surfaces

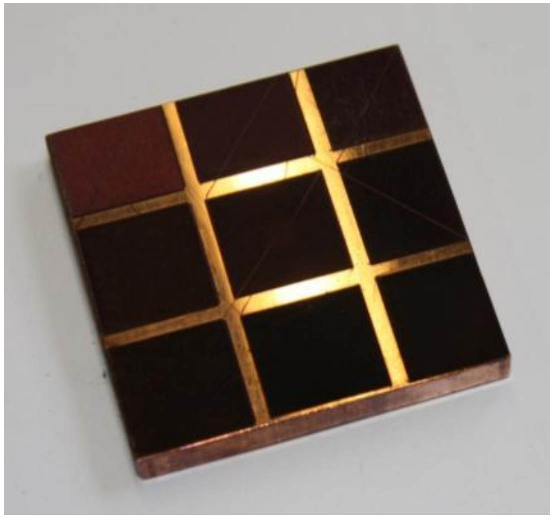


- Contact angle 174°
- Rejection of capillary leads to slipping of the drop
- Drop sticks to non-structured surface



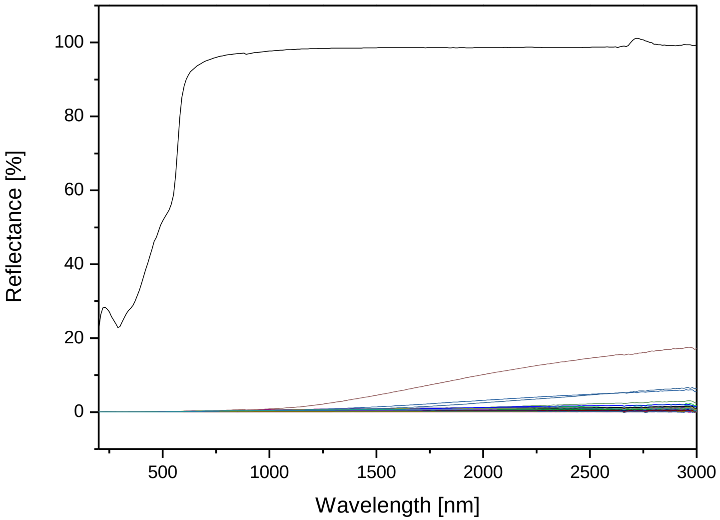
- Contact Angle <5°
- Complete wetting of the surface

Black Metal



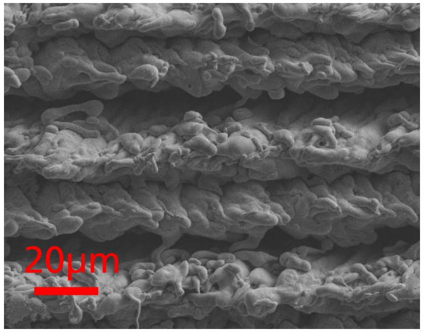
Modification of metal surface properties by a combination of micro and nano structures

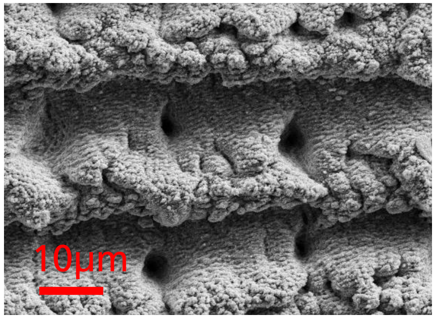
- Solar energy
- Catalysis
- Measurement technology



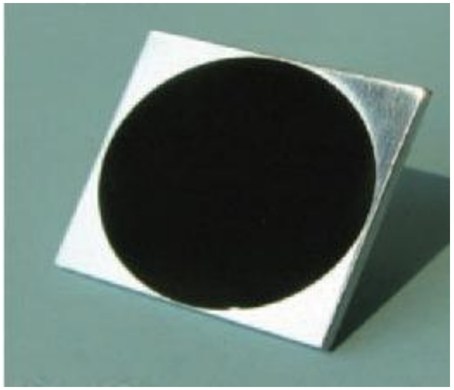
- > 1 cm^2/s
- Absorption > 98% (250-3000 nm)
- Hydrophobic or hydrophilic surfaces

Fs-laser structured copper surfaces (oxides removed by chemical etching)



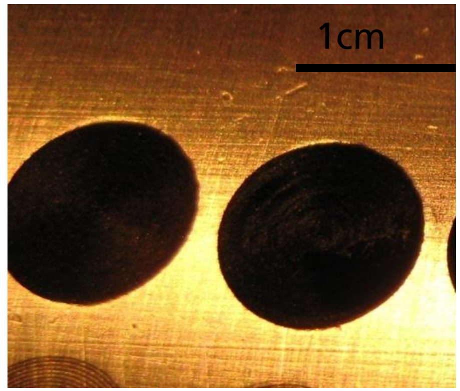


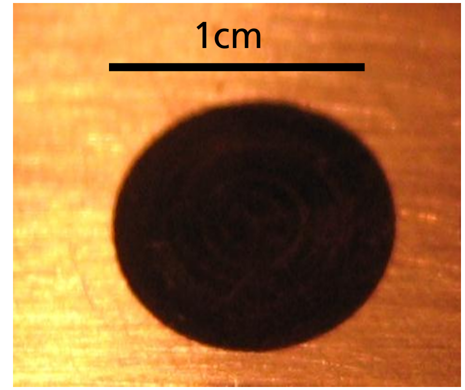
Ablation – Surface Texturing



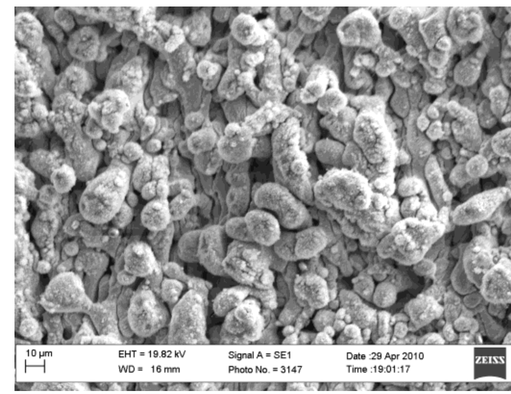
Appl. Phys. Lett. **92**, 041914 2008

“black brass”





“black copper”



A. Y. Vorobyev und C. Guo,
University of Rochester

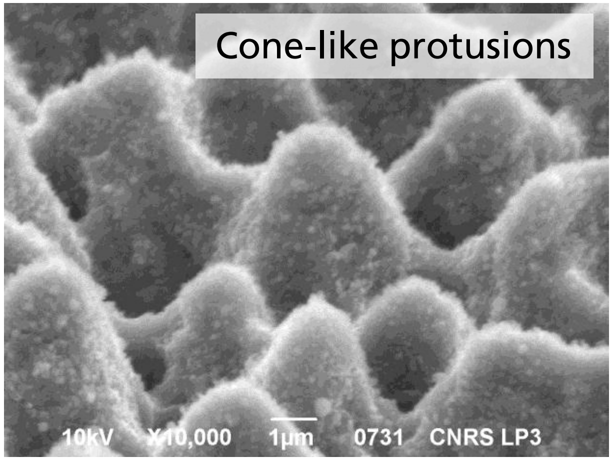
Ti:Sa: P = 1 W, f = 1 kHz, v = 1 mm/s

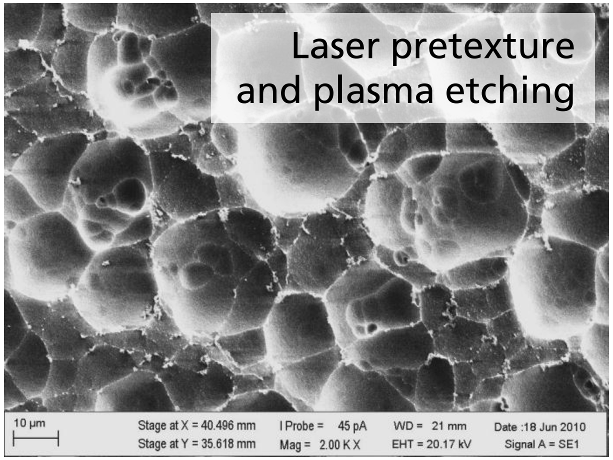
InnoSlab: P = 140 W, f = 20 MHz, v = 1000 mm/s
A = 40 mm^2/s

Control over optical properties of metals from THz to UV
by micro and nano structuring of the surface

Black Silicon

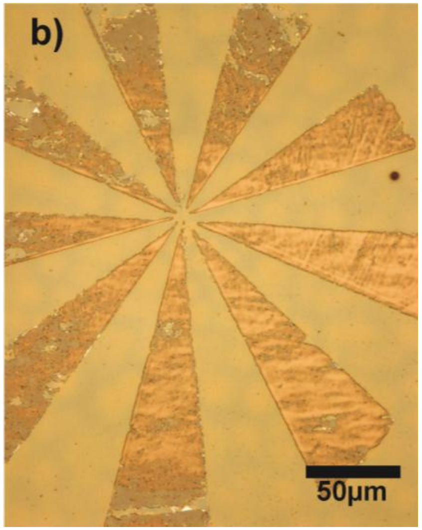
- Surface texture: reduces reflectivity and traps incident light inside solar cell
- Laser-based texturization: creation of self organized cones („black silicon“), deteriorates material quality drastically (amorphization)
- „Soft“ full-area laser irradiation in combination with chemical or plasma etching yields first results (feasibility study)
- Laser: TruMicro 5250, 515 nm, 7 ps, ~20 W
  - Fast scanning to separate pulses
  - Single pass, 16 m/s, 400 kHz
    → 38 s for a full 6 inch wafer



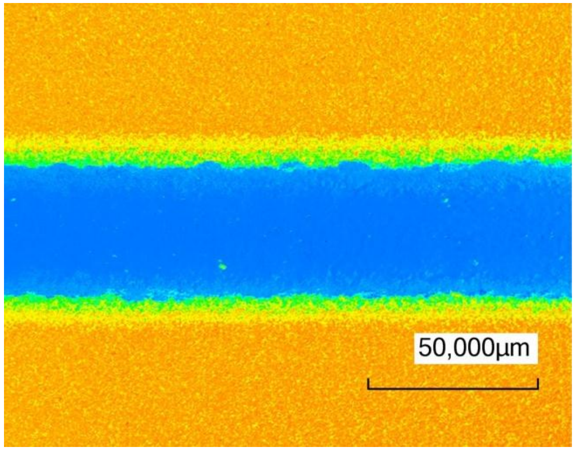


Functional Surfaces
Thin Film Processing

- 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
- Laser source
  - Excimer laser (193 nm, 248 nm, ns, mask projection)
  - Ultrafast laser (355 / 532 / 1064 nm, fs…ps, Scanner deflection)
- Applications
  - OLED lighting and display
  - Thin film PV

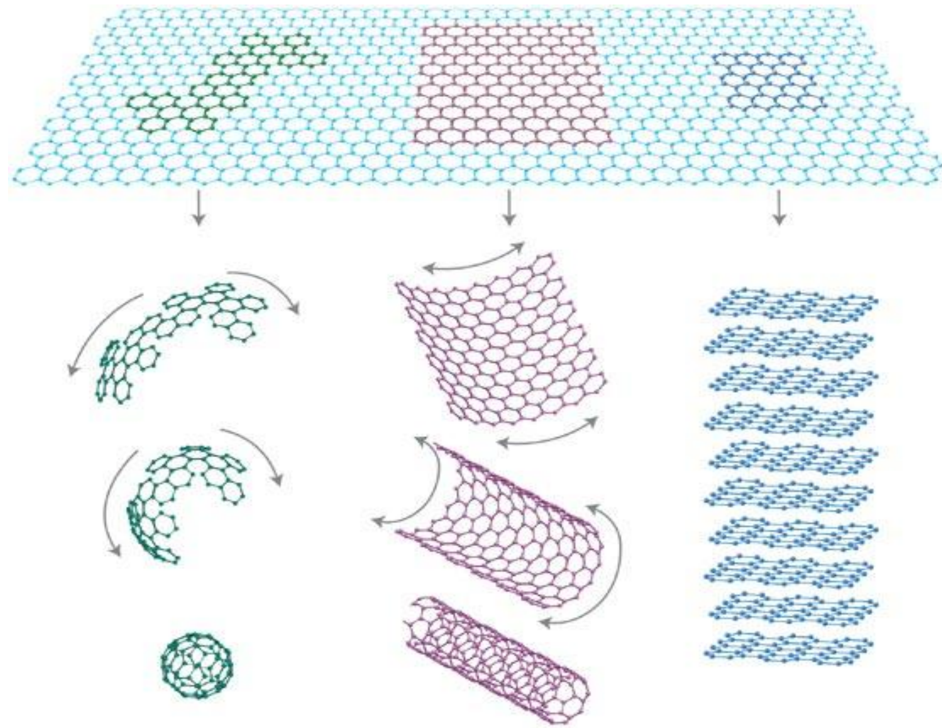


PEDOT:PSS
248 nm
s= 1.6 ± 0.2 µm



SnO on glass
10 ps, 355 nm

Graphene – Properties

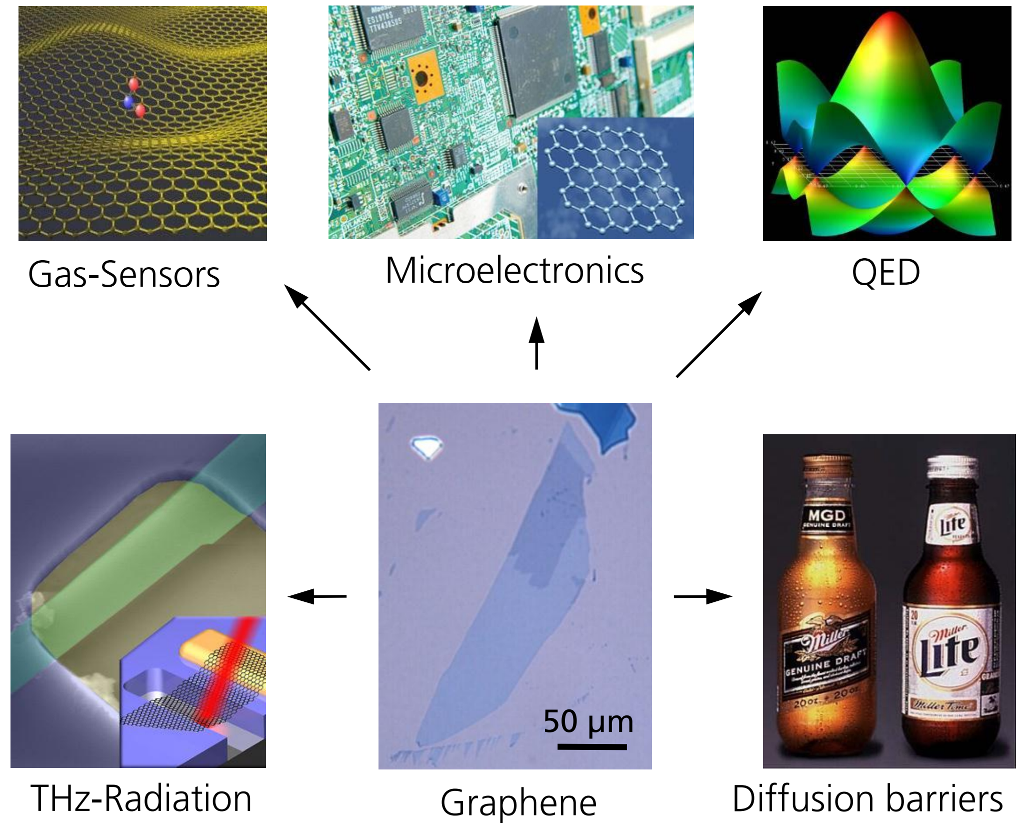


Fullerene Nano tubes Graphene

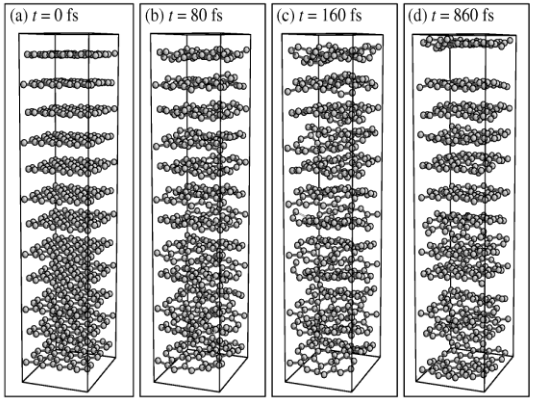
Graphene – Properties

2d Crystal,
Monolayer Carbon

- Mechanical stability
- Gas impermeability
- Ballistic charge transport
- THz emission and detection



Graphene – Production by fs-Laser



Jeschke et. Al.,10.1103/PhysRevLett.87.015003

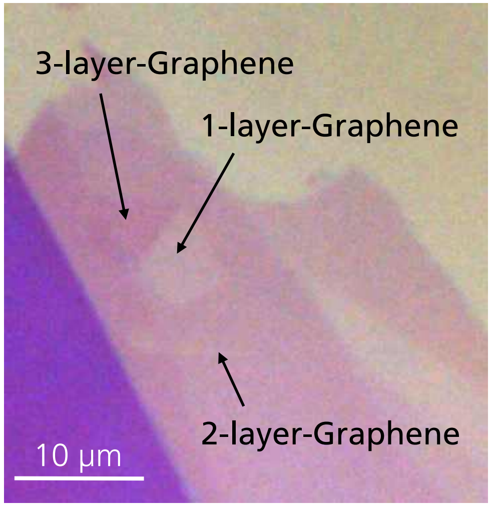
Irradiation by fs-pulses and fluence < F_{Th}

- Oscillation of individual layers
- Momentum transfer normal to surface
- Ablation top surface atomic layer

Simulation (Garcia/Jeschke): non-thermal Ablation of single atomic layers

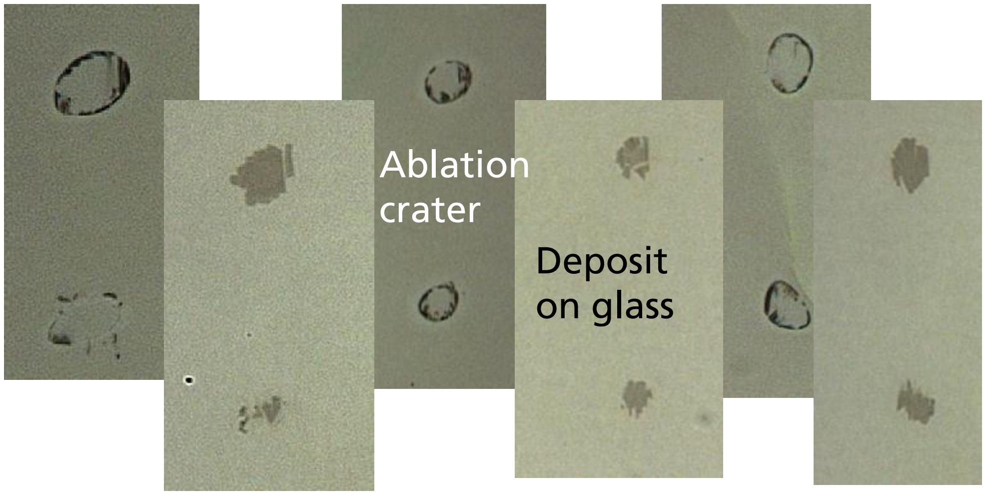
Molecular resonance @ 106 µm (0,01 eV)

Silicon surface

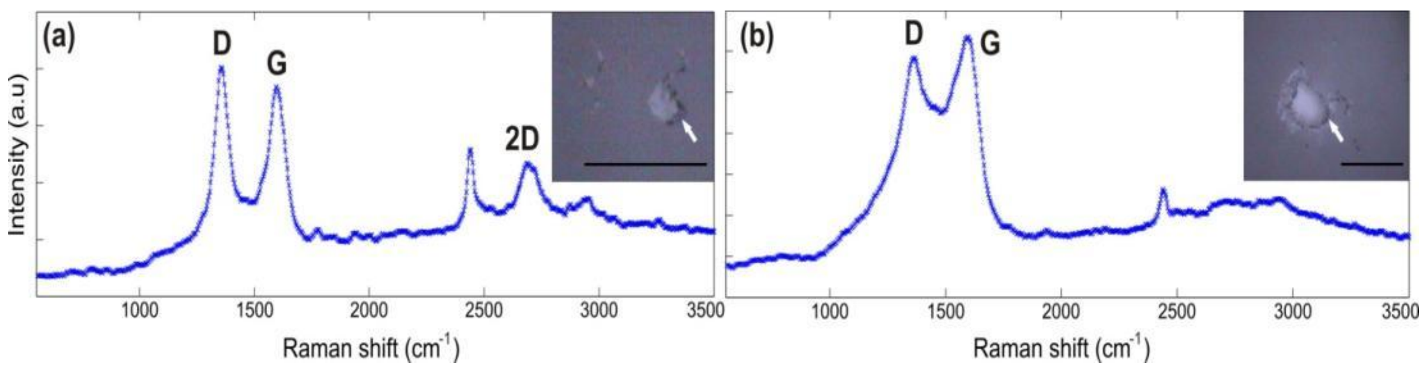


Experiment (ILT): Demonstration of single atomic layer

Graphene



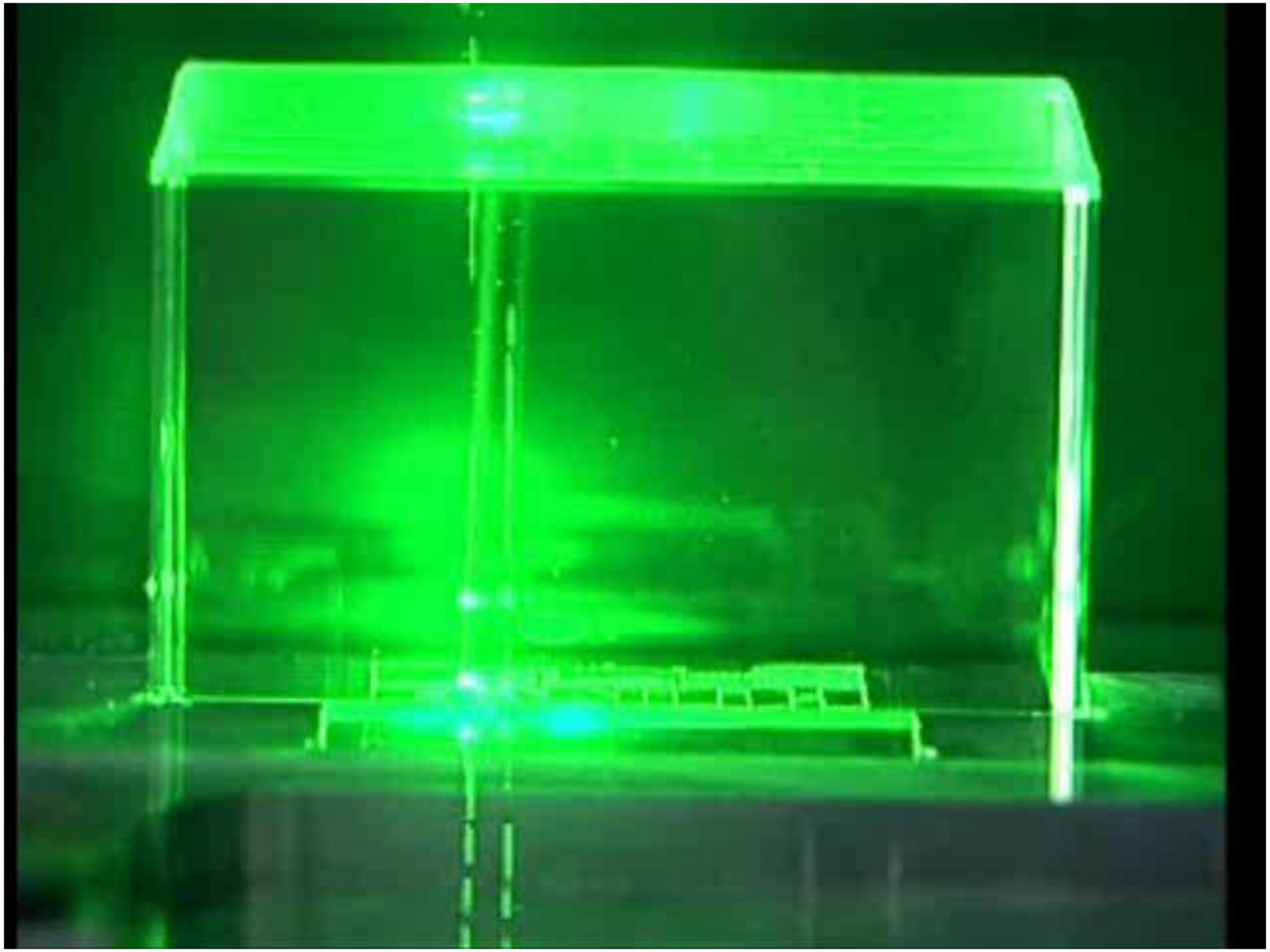
Deposition of crystalline flakes on glass
Deposit fits to the ablation crater
→ no ablation by melting or vaporization



Raman spectra of carbon deposits at different pulse energies

In-Volume Selective Laser Etching: ISLE

Laser In-Volume Structuring

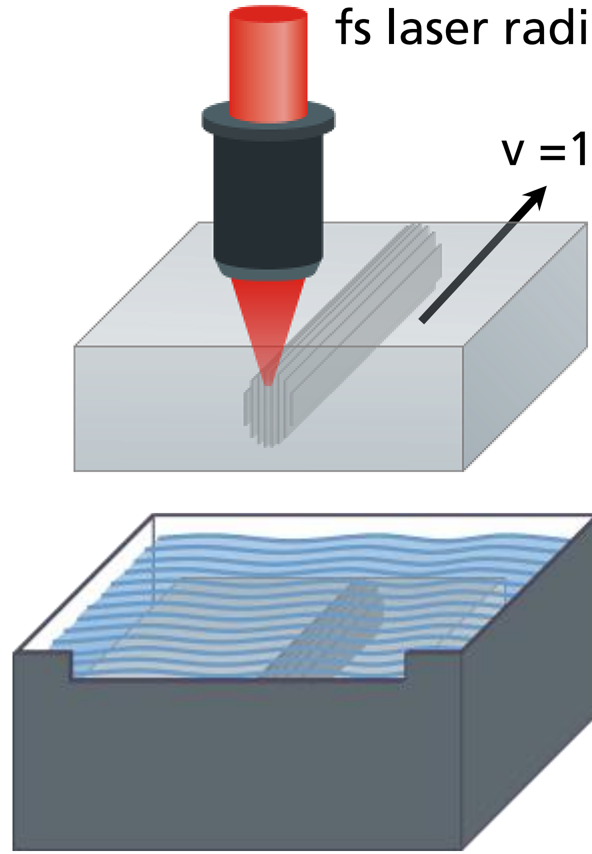


In-Volume Selective Laser Etching, “ISLE”

Processing steps:

1) Selective modification of the structure in the volume by fs laser radiation

2) Selective etching of the modified structure



Examples for High Speed In-Volume Micro Structuring

Gears made of fused silica

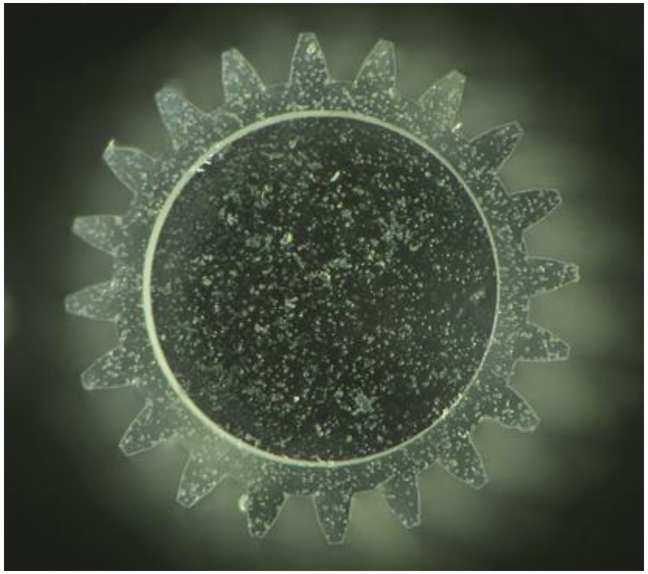
Material thickness, height: 1 mm

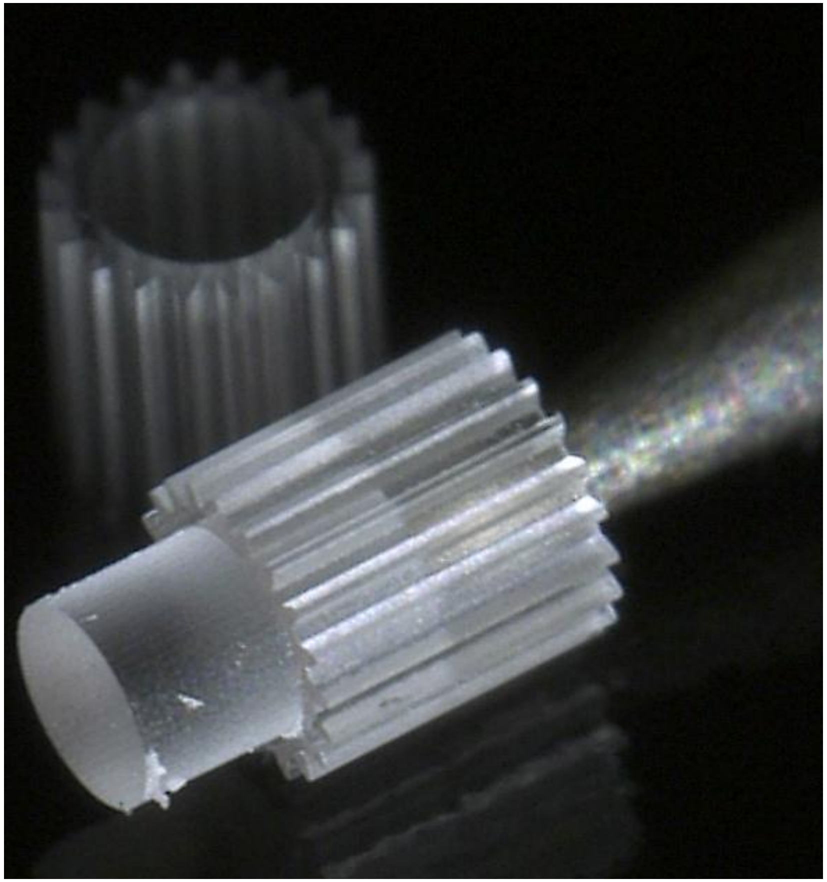
v = 100 mm/s

P = 200 mW

NA = 0.3

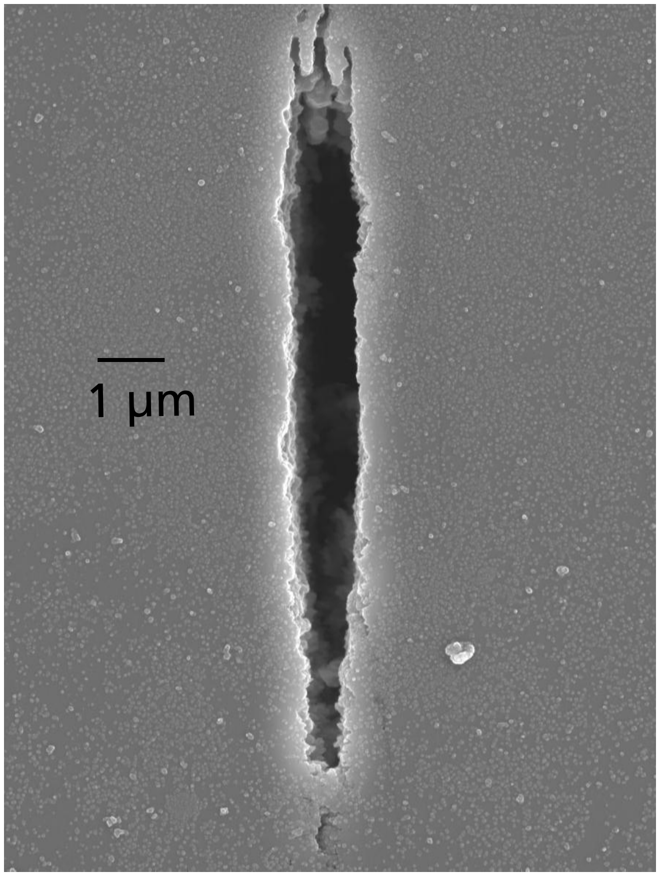
Processing time: 400 s





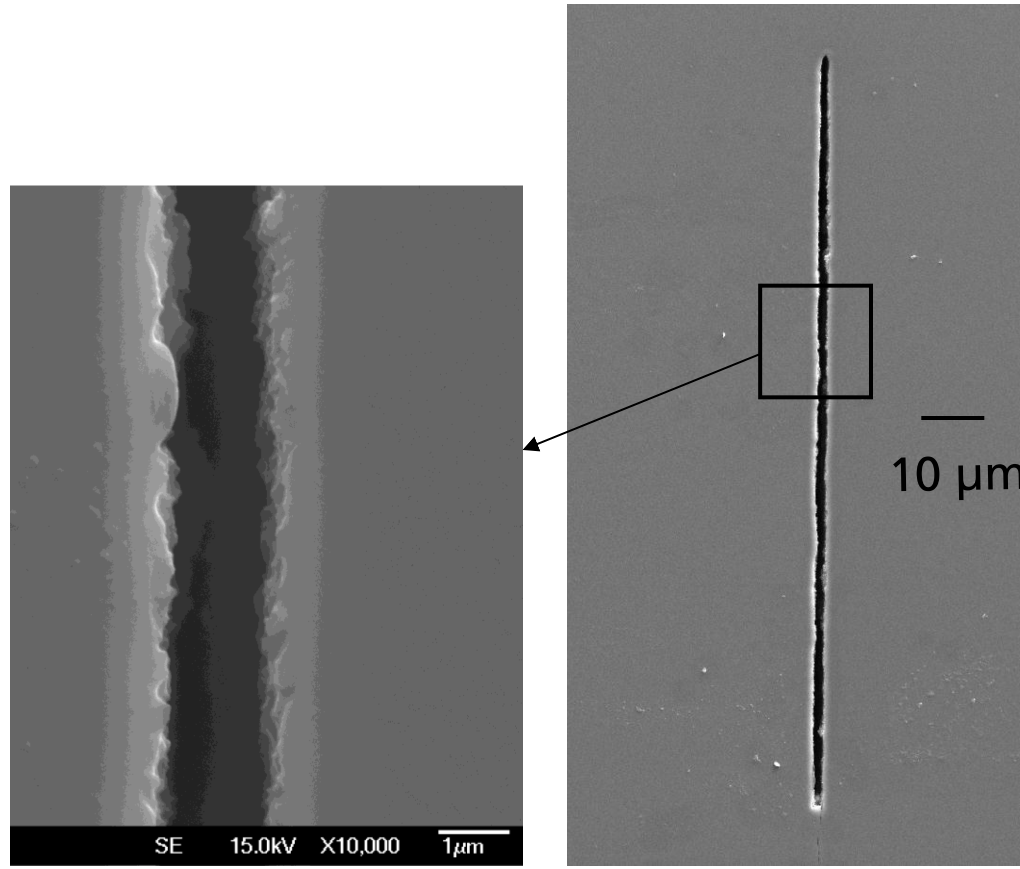
Micro Structuring of Sapphire by ISLE

Cross-section of micro channel



→ Length 10 mm

- Cross-section of micro slit in sapphire



→ Length 10 mm, height 125 µm, width 1 µm

Fraunhofer
ILT

Examples for High Speed In-Volume Micro Structuring

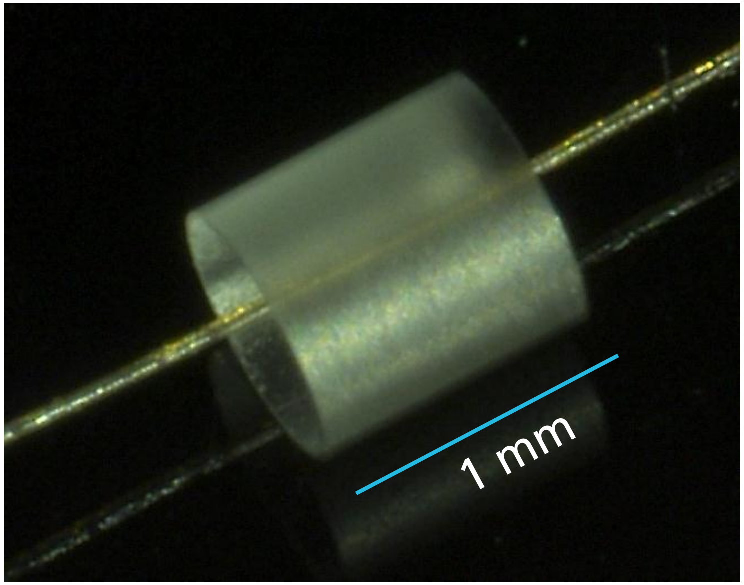
Tubes made of fused silica

Diameter and height: 1 mm

v = 25 mm/s

P = 250 mW

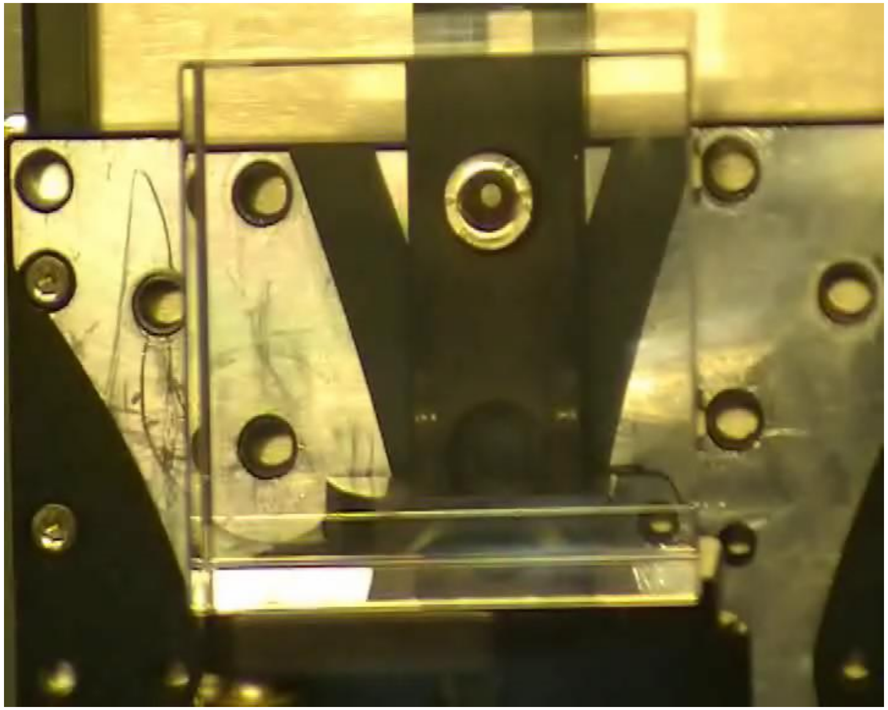
NA = 0.3



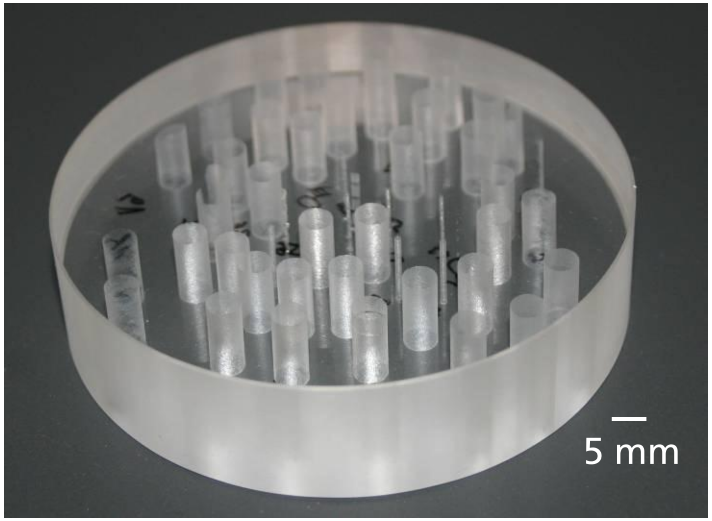
Outlook: ISLE with High Power 400 W fs-radiation

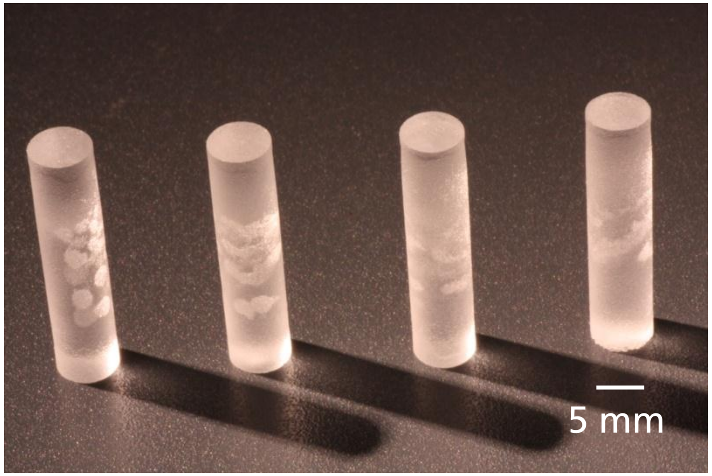
Very fast modification of cylinders demonstrated – First results

- fs-slab from ILT (400 W, 700 fs, 20 MHz)
- Scanning velocity 3 m/s



Modification of cylinders in BK7 (P = 60 W, 7 s)

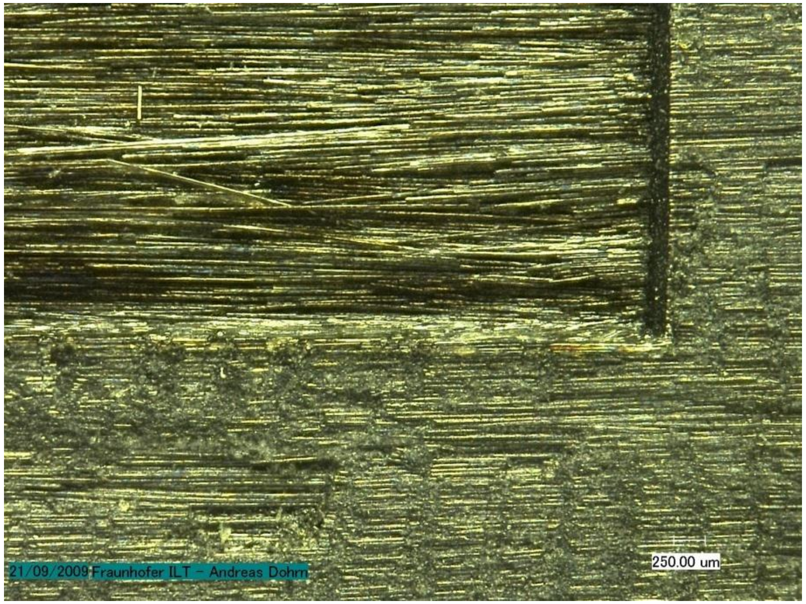


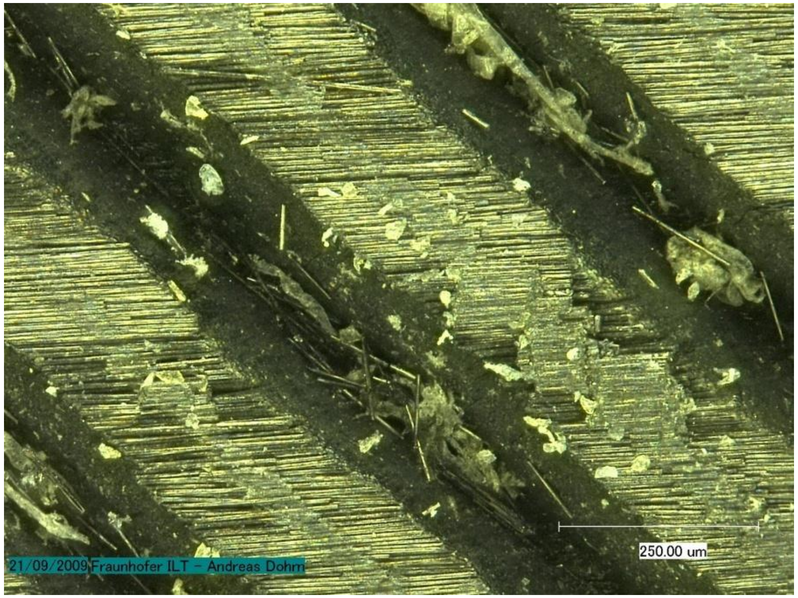


Cylinders in fused silica (P = 25-80 W)

Volume Ablation by Ultrafast Lasers / Structuring

Multipass-Ablation of Carbon Fiber-Reinforced Polymers





Pulse duration 10 ps
Repetition rate 100 kHz
Pulse energy 30 µJ
Scan speed 1m/s
Ablation per layer 10 µm

Pulse duration 100 ns
Repetition rate 100 kHz
Pulse energy 50 µJ
Scan speed 1m/s
Ablation per layer 20 µm

Multipass-Ablation of Glass Fiber-Reinforced Polymers

Pulse duration 10 ps

Repetition rate 100 kHz

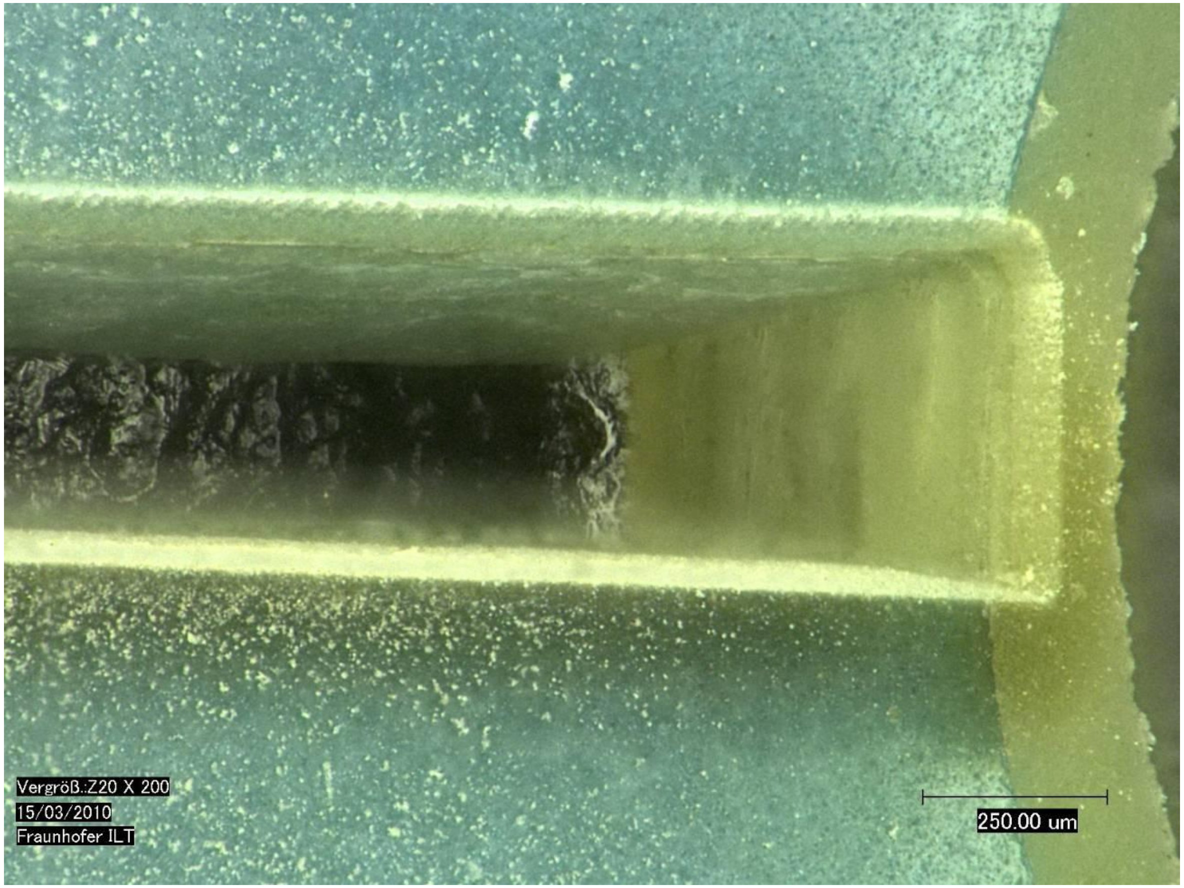
Pulse energy 30 µJ

Focus diameter 25 µm

Scan speed 1m/s

Ablation per layer 25 µm

Number of pulses ~70

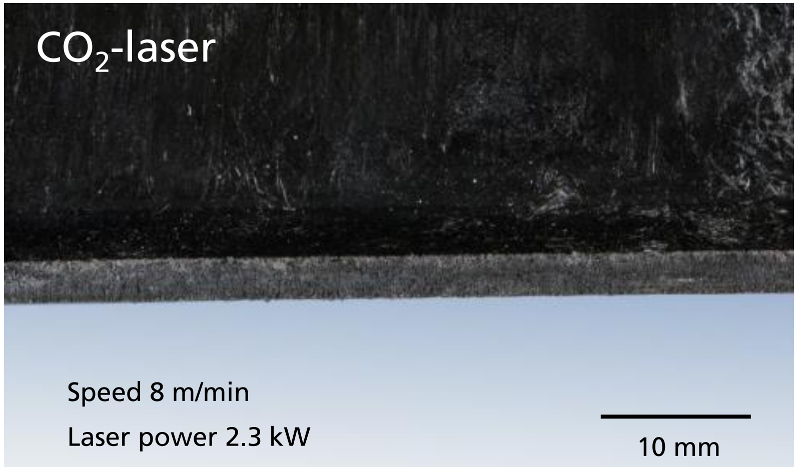


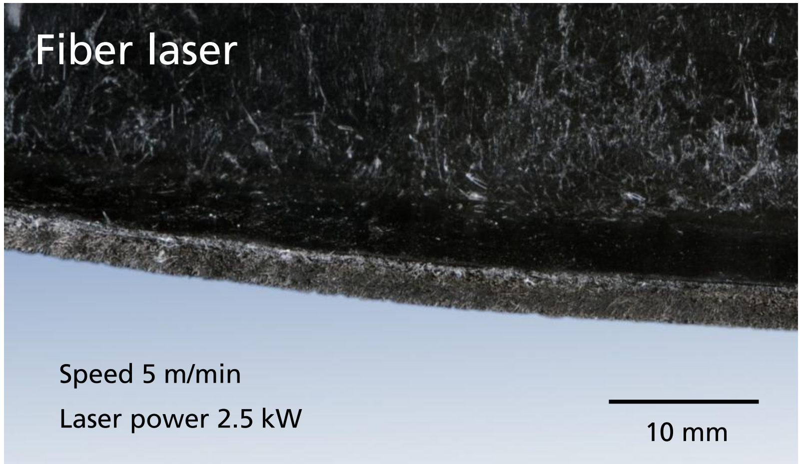
Cutting of Glass Fiber-Reinforced Polymers

- Challenge
  - reduction of heat affected zone
  - clean surface
  - material composition: varying
    - reinforcement materials
    - fiber content and orientation
    - thickness
    - in one component
- Approach
  - pulsed laser
  - optimized process gas flow

Polypropylene with 30-50% glas fiber reinforcement

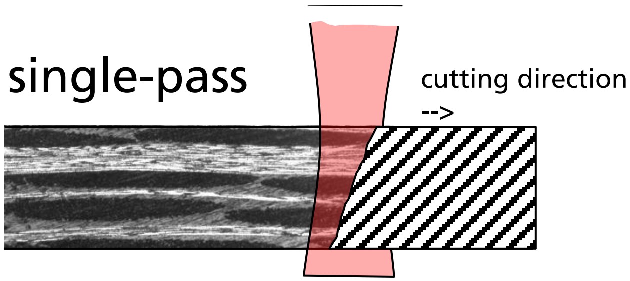
Thickness 4 mm





Cutting of FRP: Strategies for short interaction times

single-pass

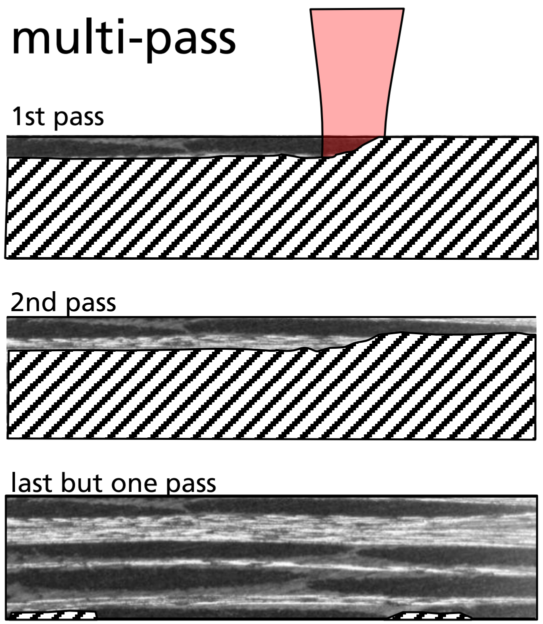


+ high speed

limited to thin materials

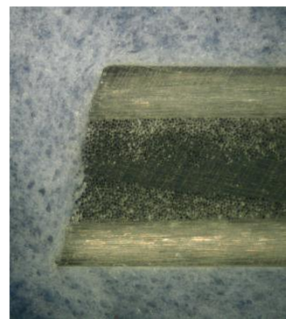
+ pulsed laser beam

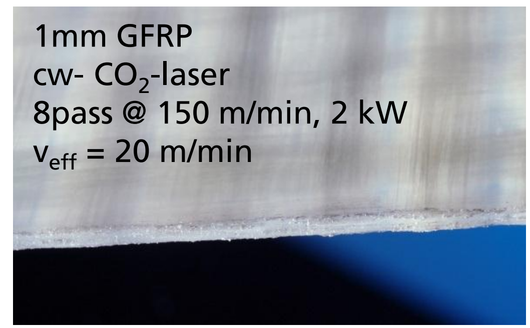
multi-pass



intermittent fast advance of the absorption front

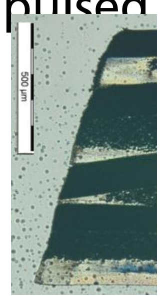
+ high speed

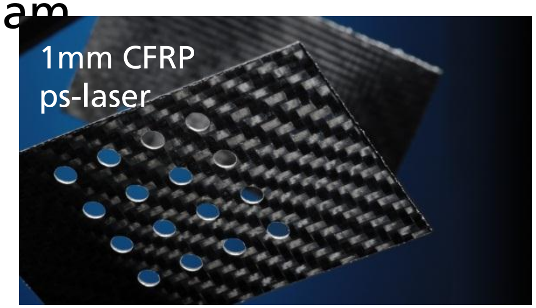




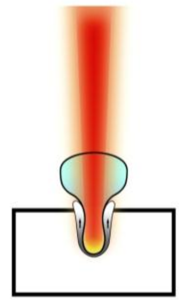
+ high speed

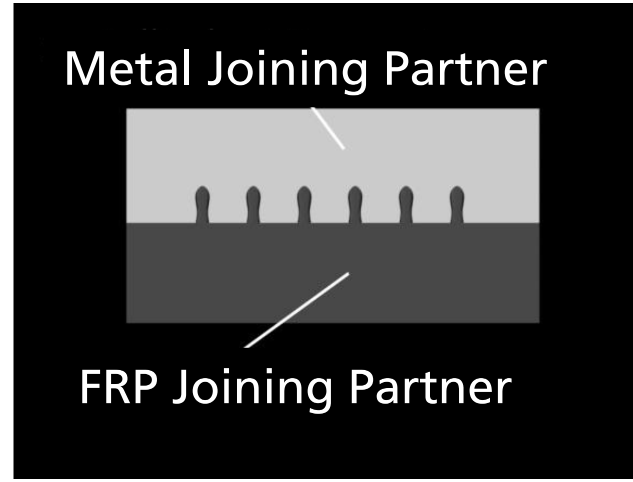
+ pulsed laser beam





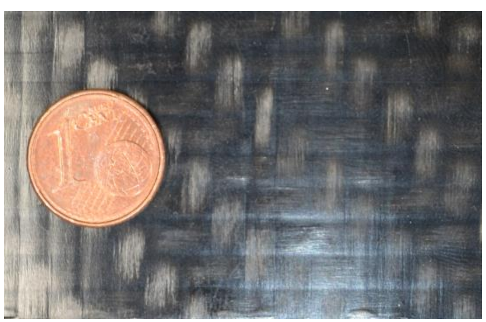
Joining of FRP and Metal:
Laser Based Process Chain

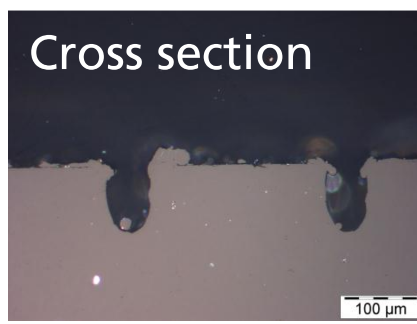


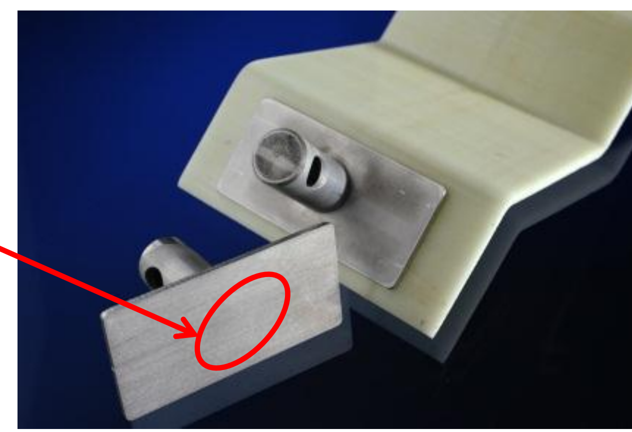


Metal Joining Partner → Laser Surface Structuring → Laser Joining

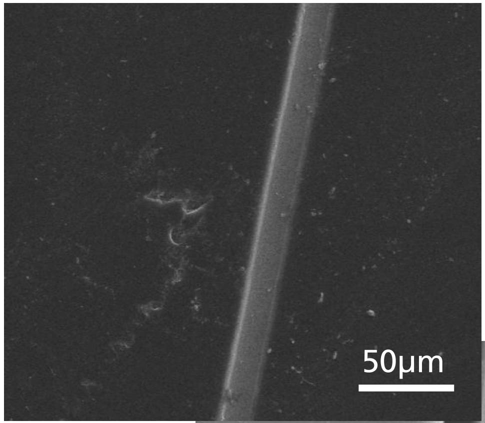
FRP Joining Partner → Laser Joining



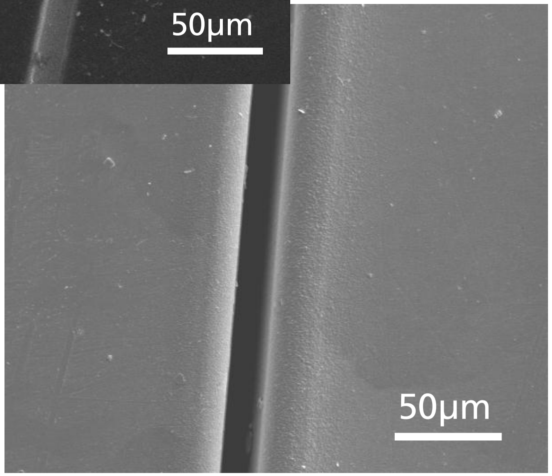


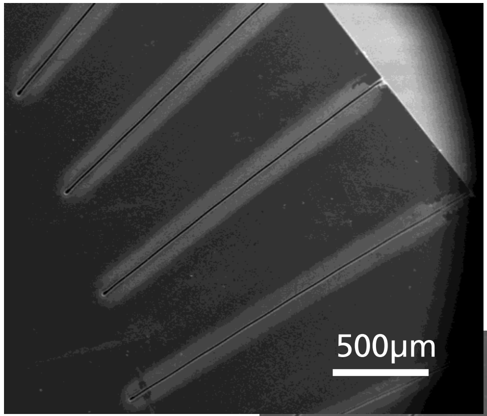


Ablation – Glassy Carbon



fs-fiber laser
τ = 500 fs
E_P = 0.8 µJ
f = 100 kHz
v =1 mm/s

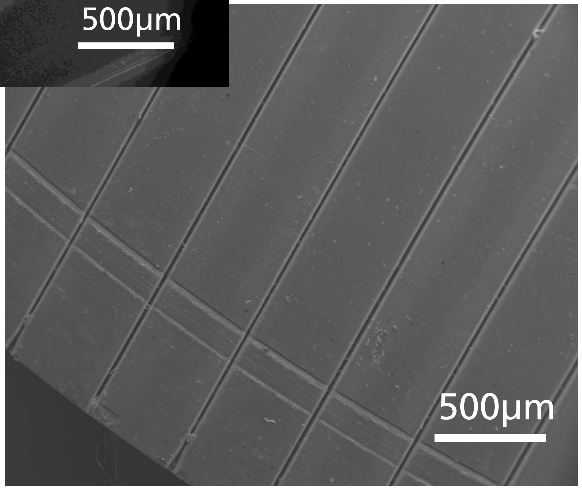




cw-fiber laser
P_m = 50 W
v = 90mm/s

InnoSlab

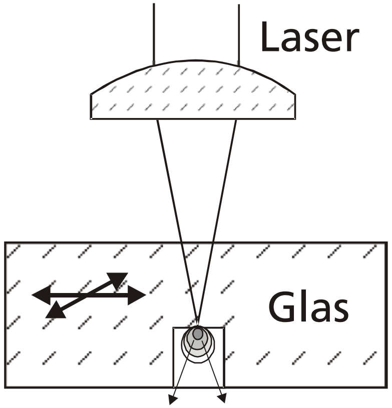
τ = 680fs, E_P = 0.8 µJ
f = 76 MHz
v = 90 mm/s

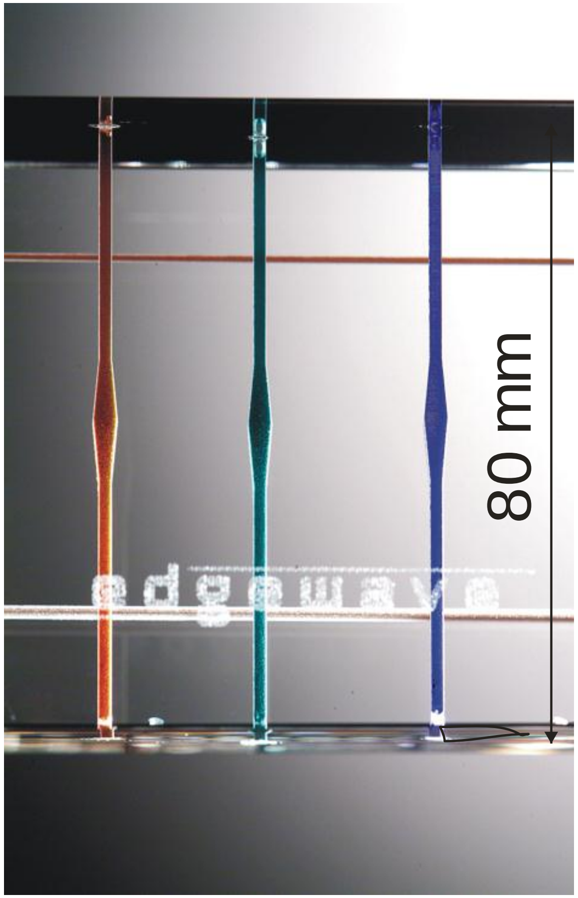


Structuring of glassy carbon SIGRADUR®:

Much higher ablation rate at 90 times higher velocity
Much less debris at the same efficiency (compared to cw-fiber laser)

Laser In-Volume Ablation





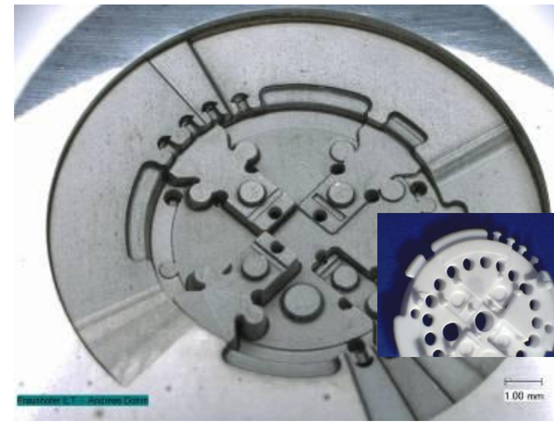
Linear Scanning Glass Ablation

Ablation rate: up to 3 mm³/s @ 150 W output power

Basics

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

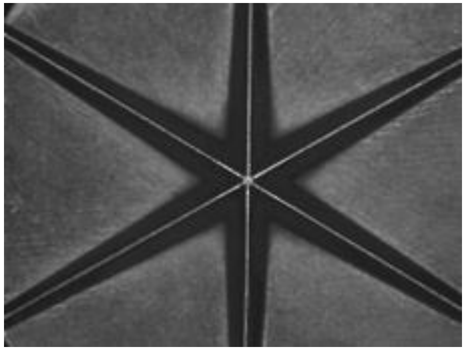
Structuring of Embossing and Injection Molding Tools

Mint 1 (Ra < 0.3 µm, 26 h)

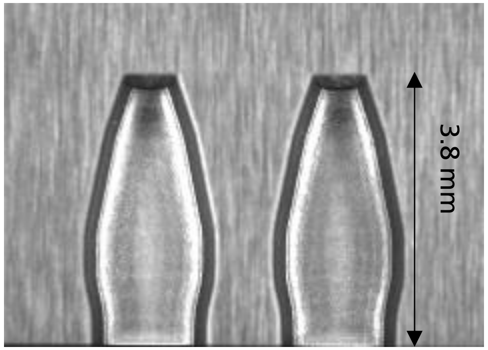
Mint 2 (Ra < 0.3 µm, 11 h)

Mint 3 (Ra < 0.3 µm, 2.5 h)

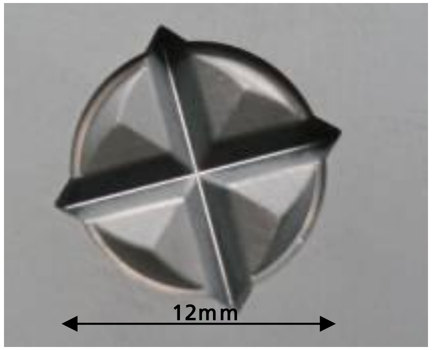
Star(d = 8 mm, t = 0.5 mm, 1.5 h)



Die (Ra < 0.3 µm, t = 0.6 mm, 35 min)



Die pellet (t =1.4 mm, 10 h)



Laser power 10 W @10 ps

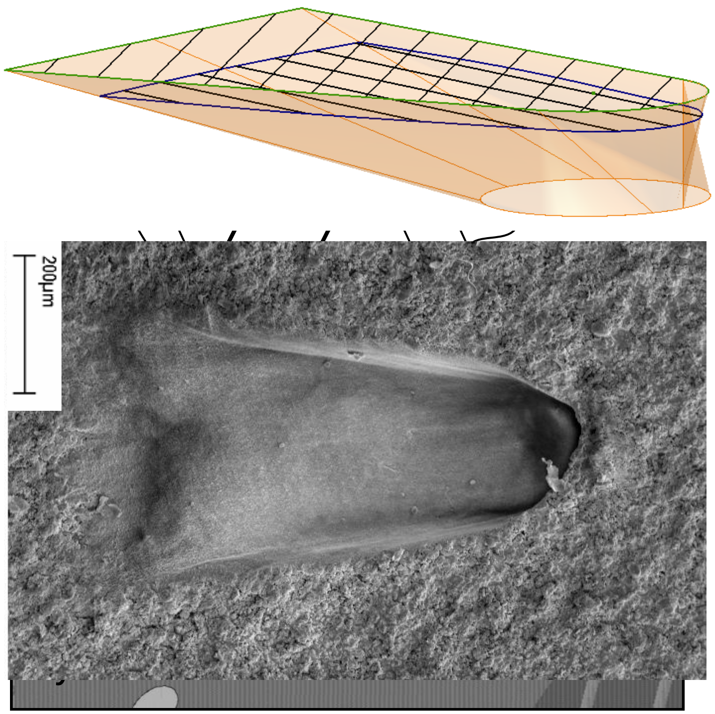
Pulse energy 5 µJ

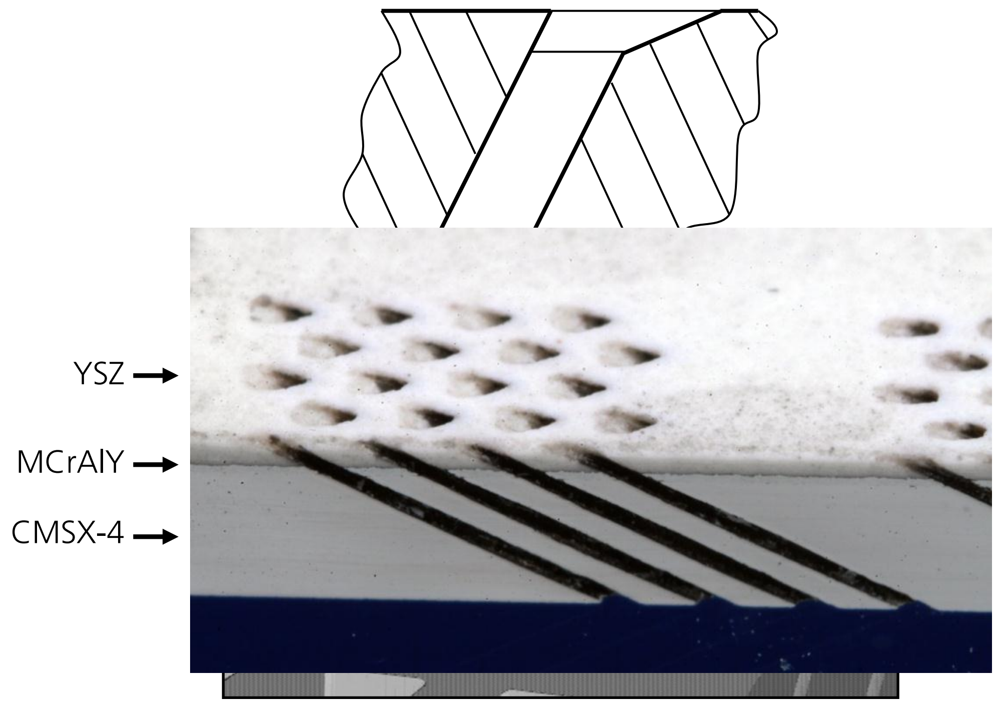
Spot size 20 µm

SAUER

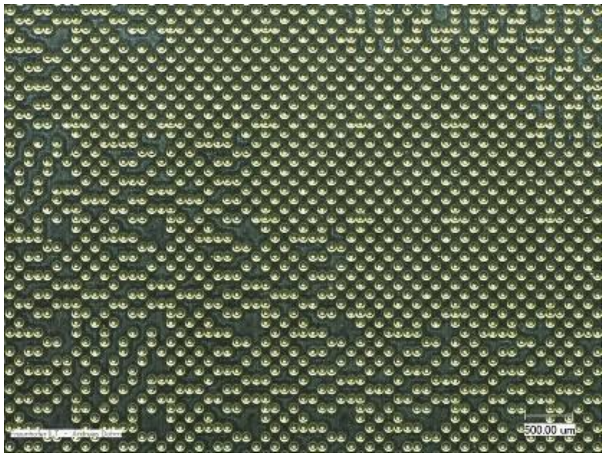
Shaping of Turbine Blade Cooling Chanel Exit Fans

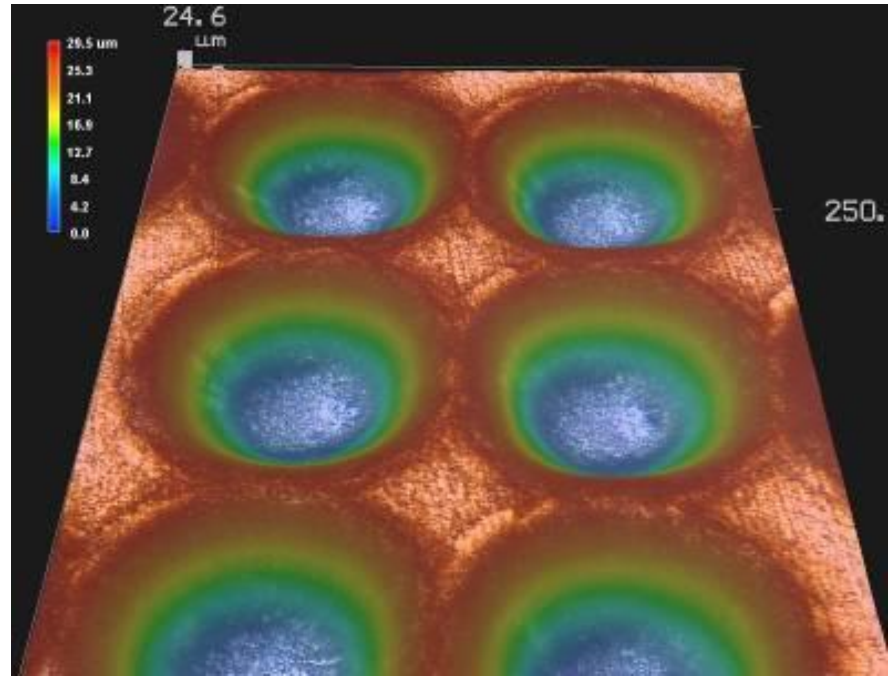
- Instead of few large holes numerous, small, and contoured holes
- Developement of homogenous cooling film by additional hole shaping





Micro Injection Moulding of Lens Arrays with ps-Laser





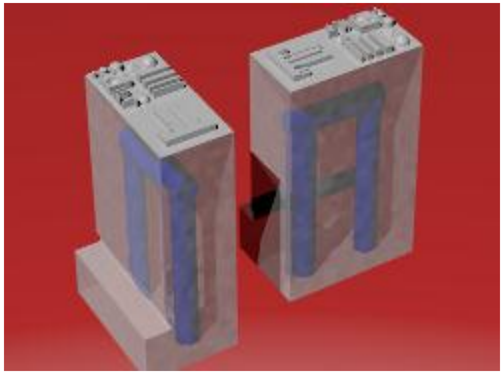
Surface quality

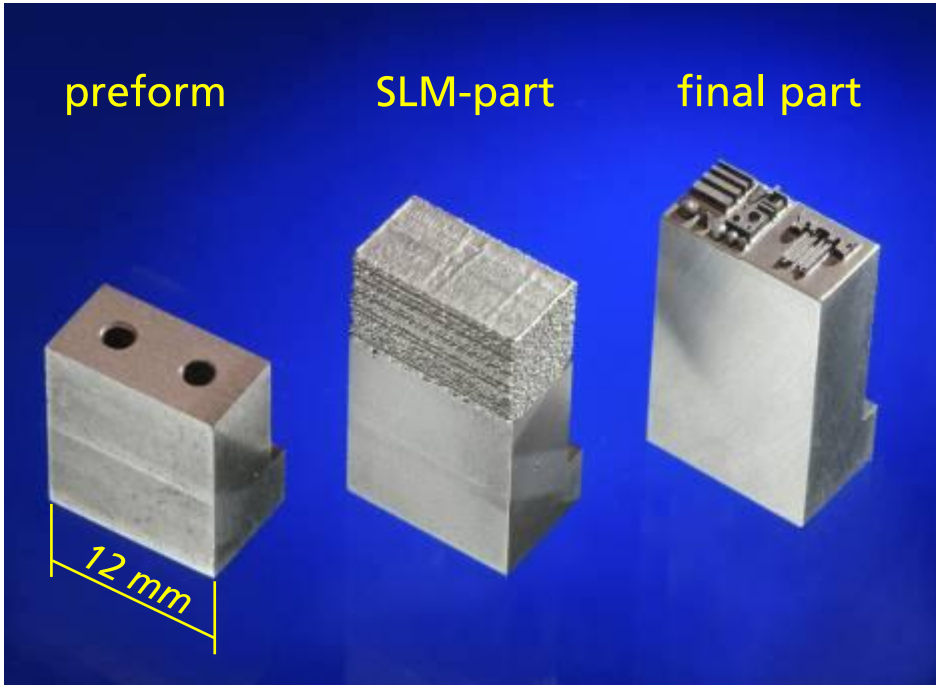
- After laser ablation: R_a = 300 nm
- After laser polishing: R_a = 100 nm

Combination of Generative and Ablative Techniques

Tool for micro injection moulding

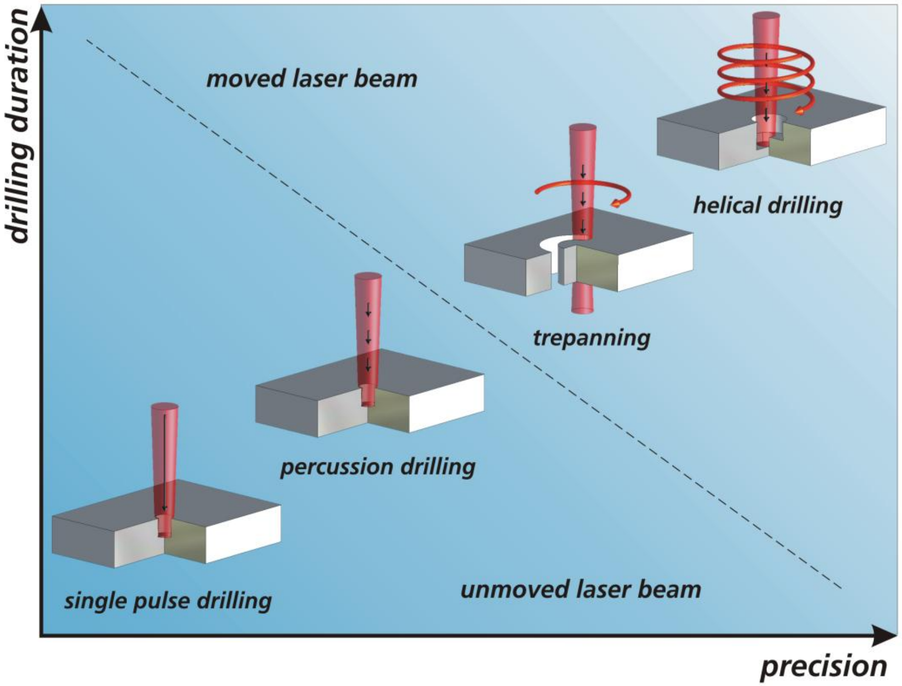
- Preform conventionally manufactured
- Generative process including cooling channels by SLM
- Functional surface by laser ablation





Drilling
Laser Drilling Techniques

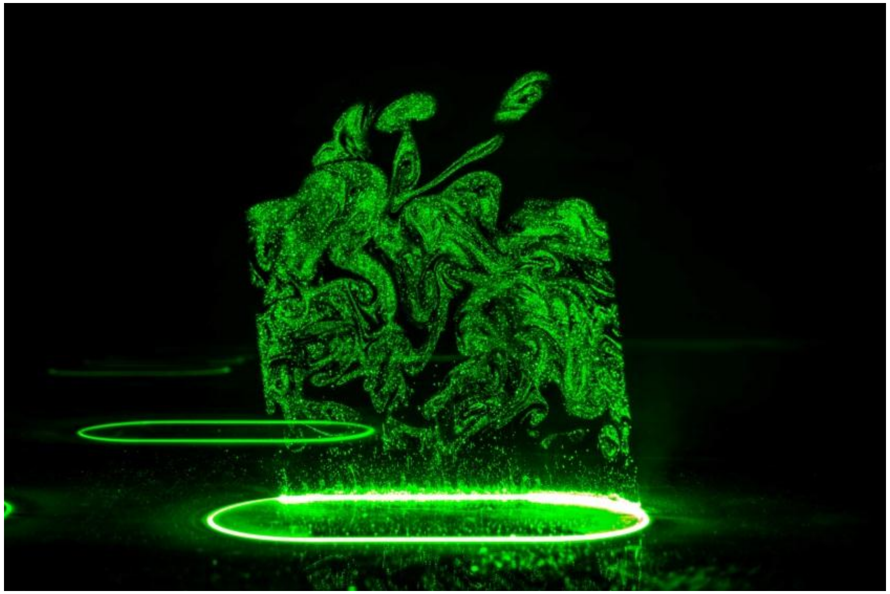
- **Single Pulse Drilling**
  - High efficiency
  - Material ablation by melting
- **Percussion Drilling**
  - Bore hole geometry depends on beam profile of the Laser
  - High aspect ratios
- **Trepanning**
  - Bore hole diameter depends on machine accuracy
  - Conical and cylindrical drillings
- **Helical Drilling**
  - Material ablation by Sublimation
  - High accuracy
  - Conical and cylindrical drillings

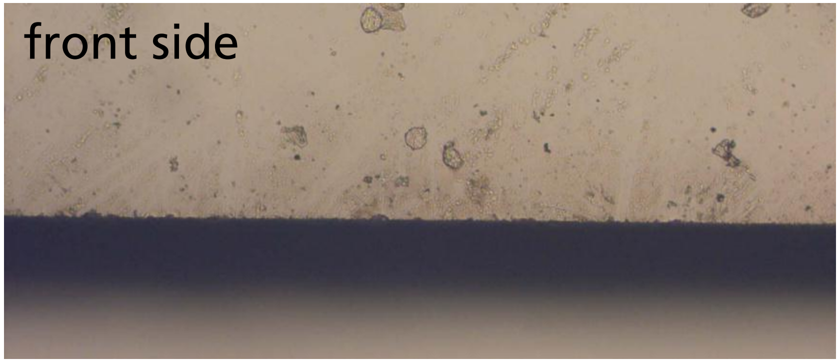


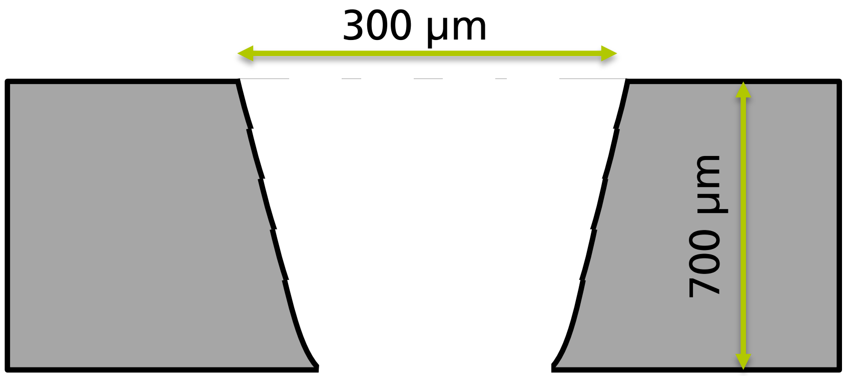
Cutting

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

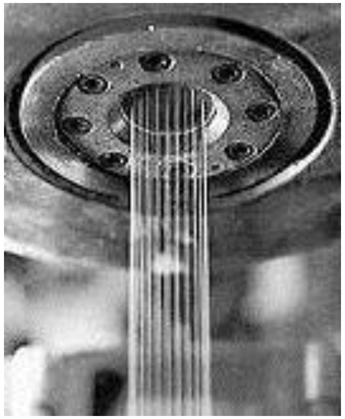


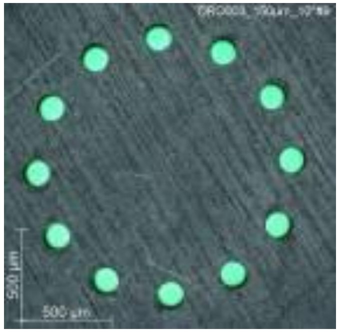


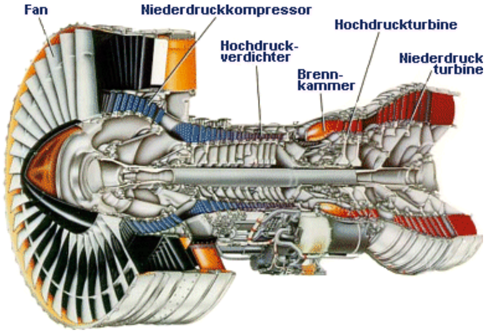


Drilling
Possible Applications

- Spray nozzle (Ø 1…20 µm)
- Micromesh (Ø 10…50 µm)
- Spinerets (Ø 10…100 µm)
- Nozzles (Ø 10…100 µm)
- Lubricating (Ø 100…200 µm)
- Cooling (Ø 100…800 µm)

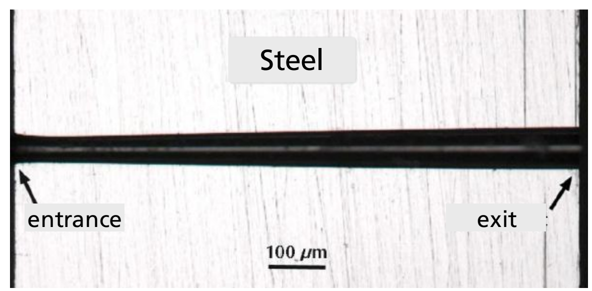


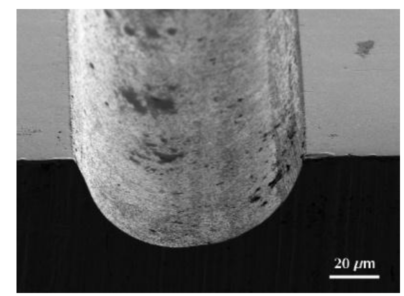




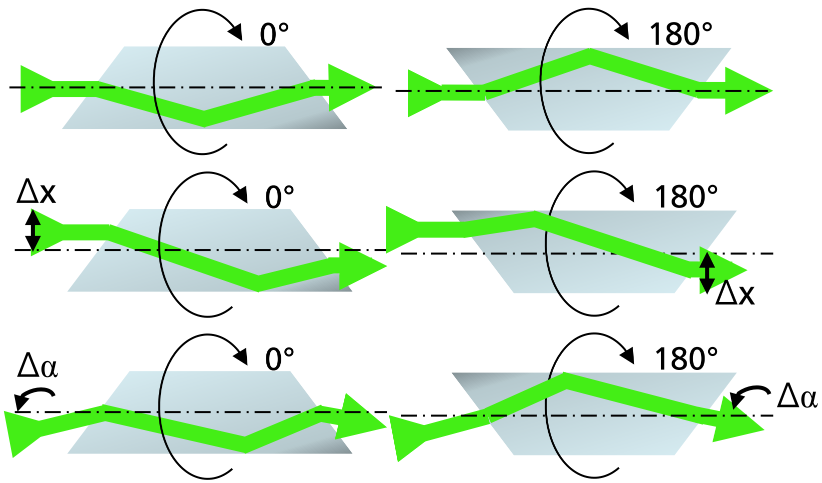
Drilling
Helical Drilling Optics

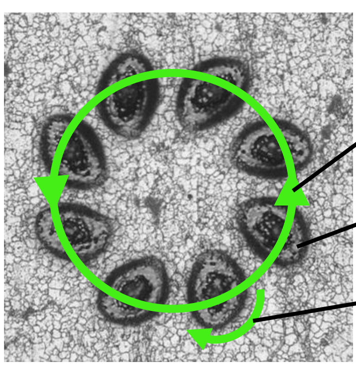
- Drilling Diameter 10-300 µm
- Conical Drilling with Tapering from 1:2 to 2:1
- Aspect Ratio up to 1:40
  Ø = 30 µm at d = 1 mm
  Ø = 40 µm at d = 2 mm





Experimental Setup
Principle of image rotating

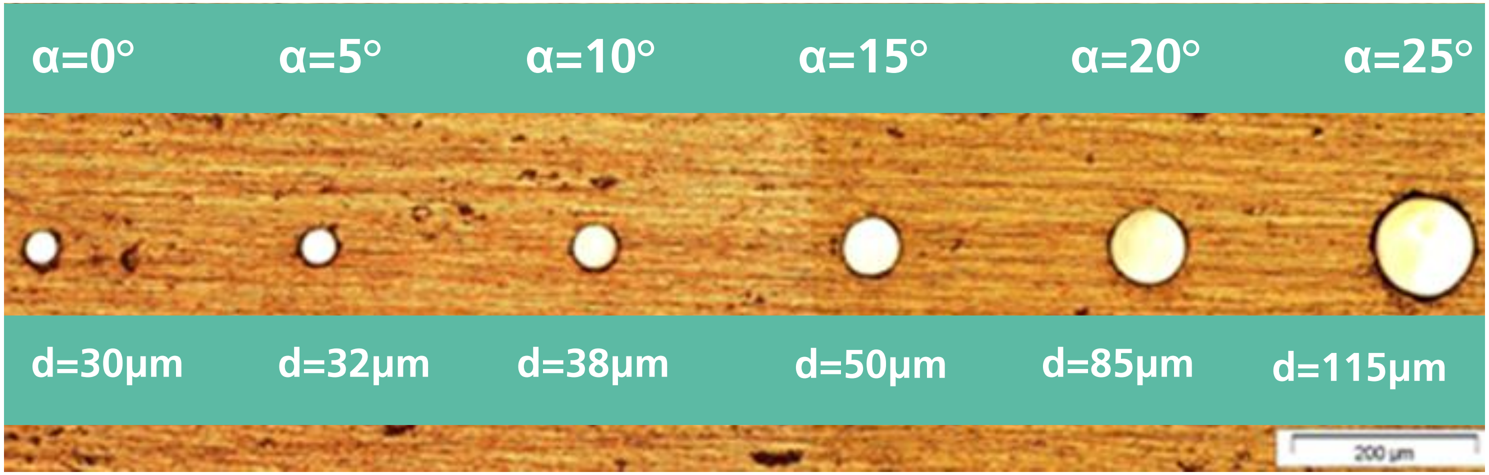


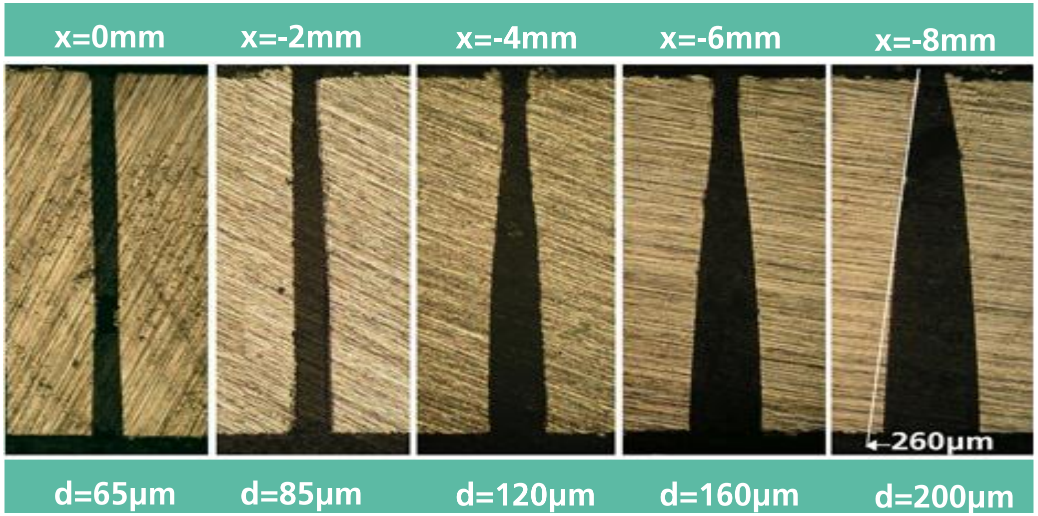


- Total reflexion inside the Dove-prism
- Rotation of the laser beam twice as fast as the prism itself (2ω-rotation)
  - Higher effective rotation speed
  - Synchronization between polarization and beam rotation
- Besides the helical movement, the laser beam is also rotating in itself
  - Independent from the beam profile, the envelope of all cross sections describes a perfect circle
  - In case of a helical diameter close to zero, the laser beam is only rotating in itself

Drilling

Helical Drilling Optics

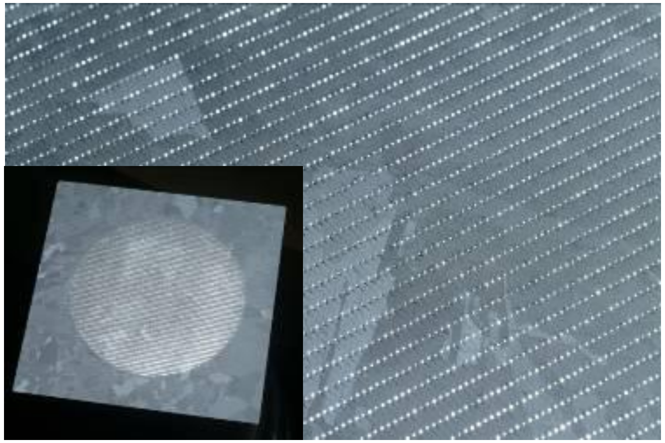


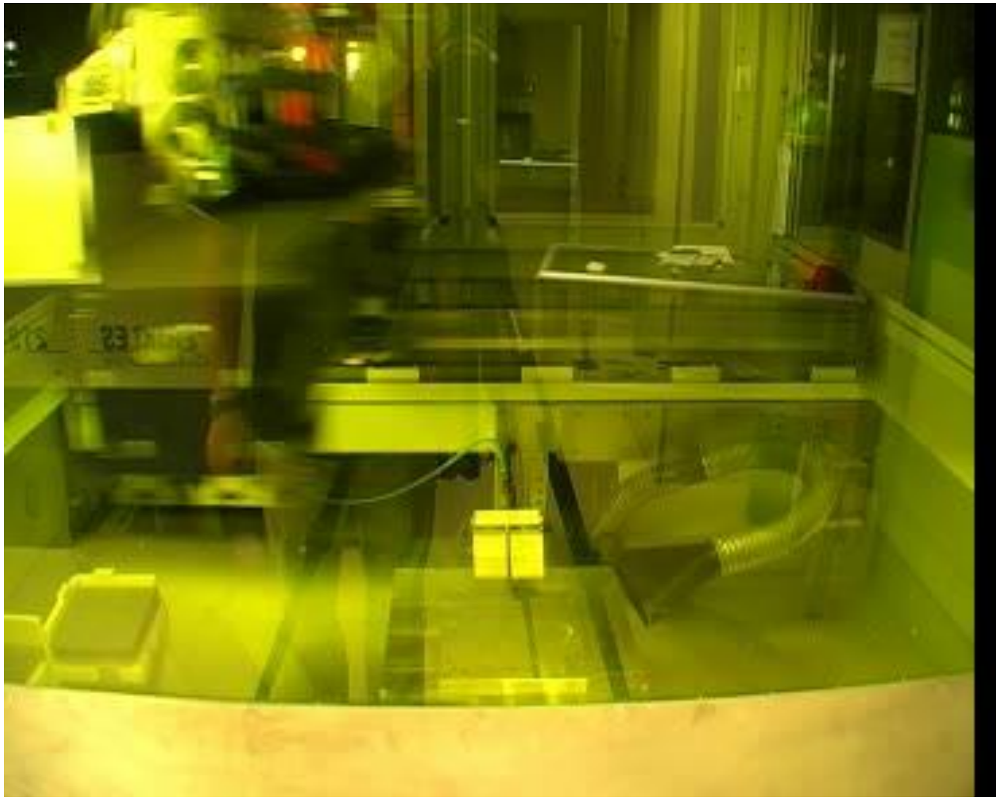


Drilling

Multi-Pass Drilling

- Q-switch Disk laser
- Scan field: 200 x 200 mm²
- Focus diameter: 50 µm
- Number of drillings: 3000 1/s
- Number of pulses: 5





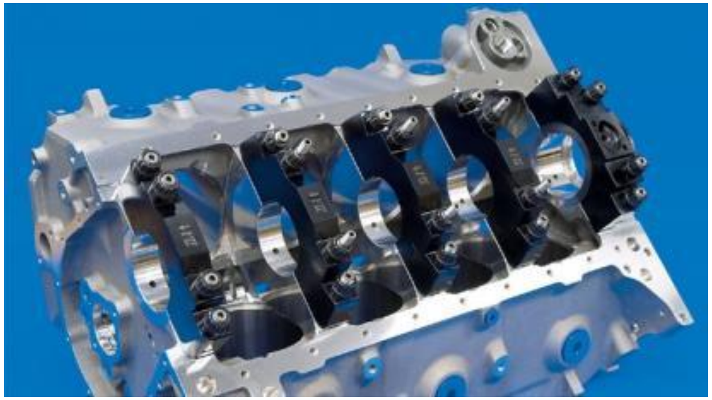
Future Developments

High Precision at Large Components

Cutting of fiber-reinforced polymers

Large area processing

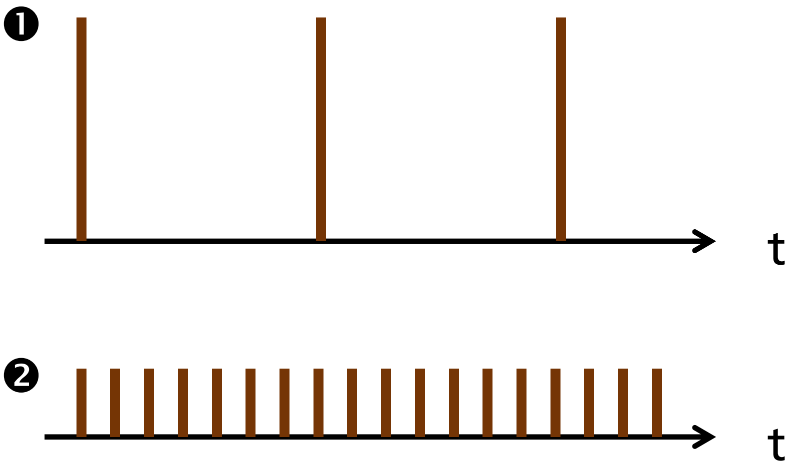
Surface structuring



Low friction surfaces

Large Area Processing

System Strategies



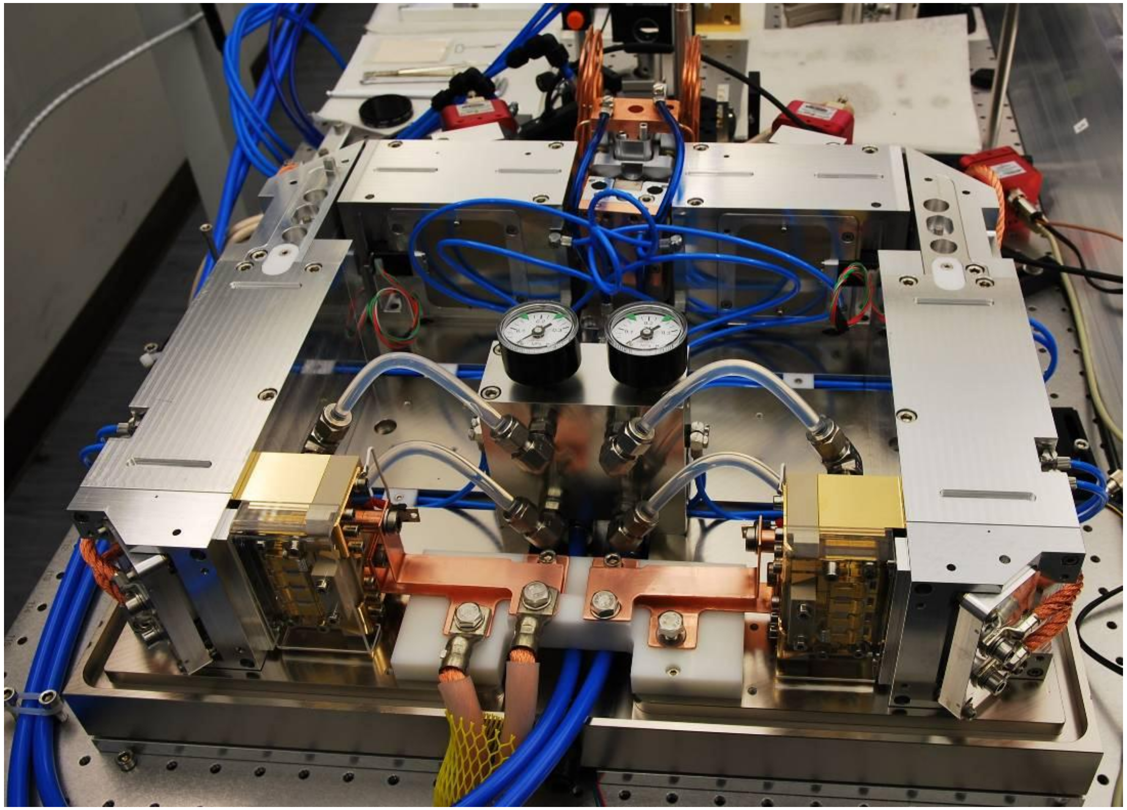
high pulse energy / low reprate?

or

high reprate / low pulse energy?

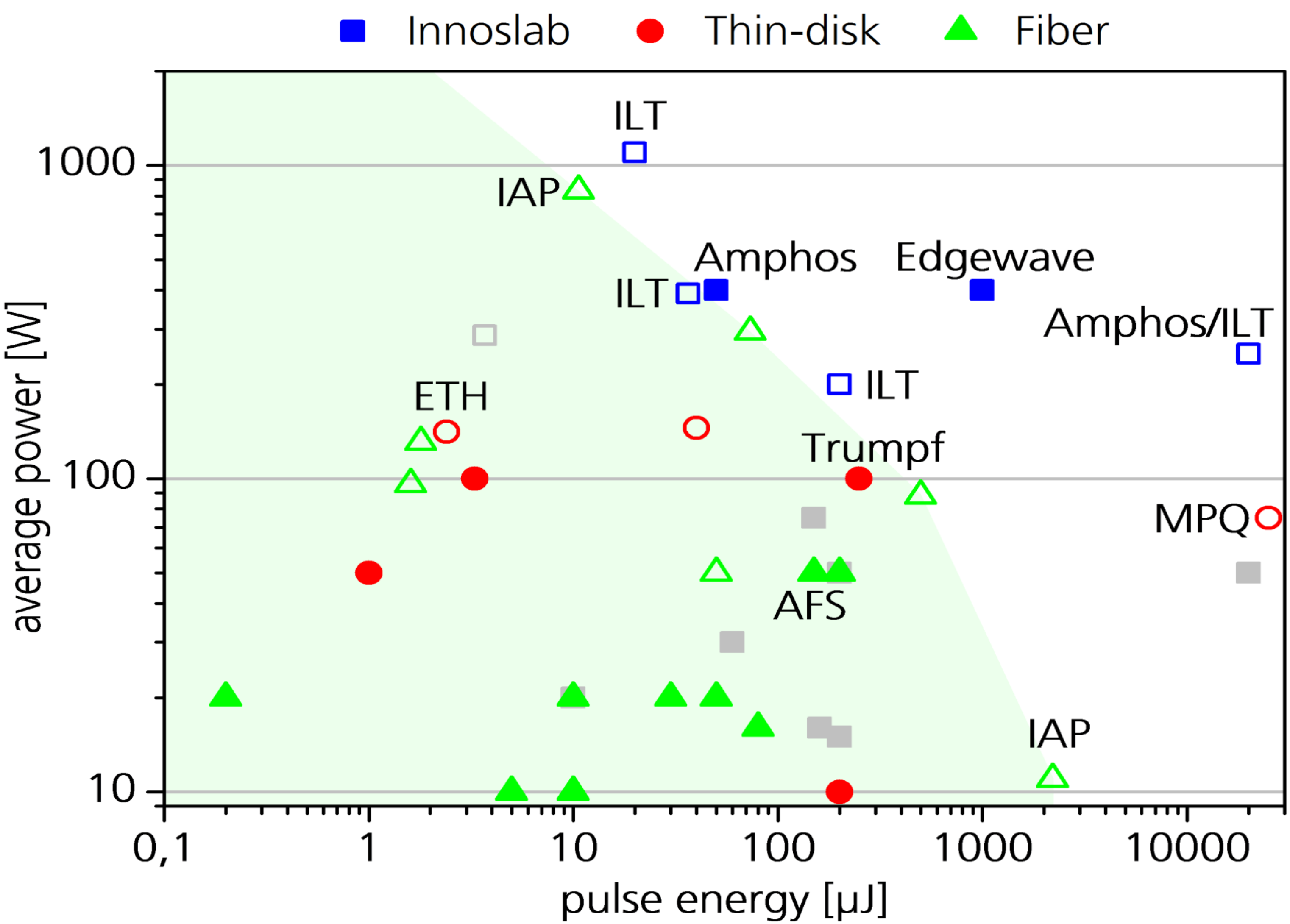
kW-Class fs-Amplifier – Laboratory Prototype

Dimension: 50 x 50 cm²

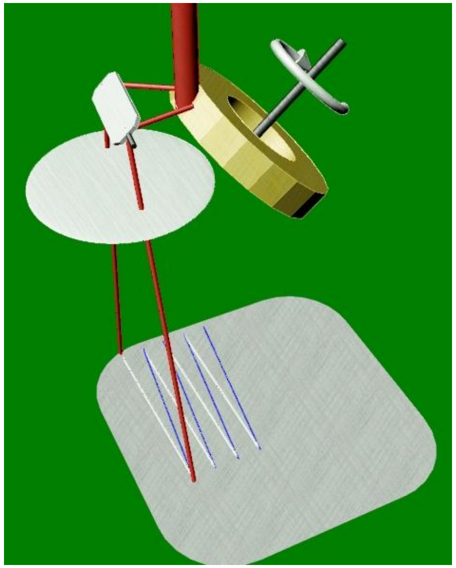


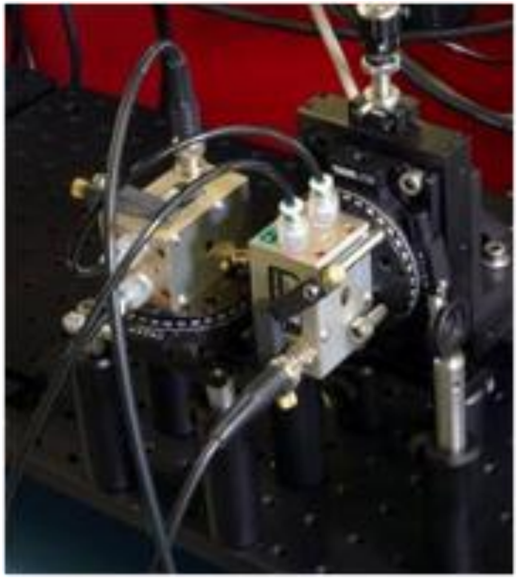
May 4, 2010, 2 am
- 1.1 kW @ 600 fs
- 20 MHz
- 55 µJ
- 90 MW peak
- no CPA
- 2 stages

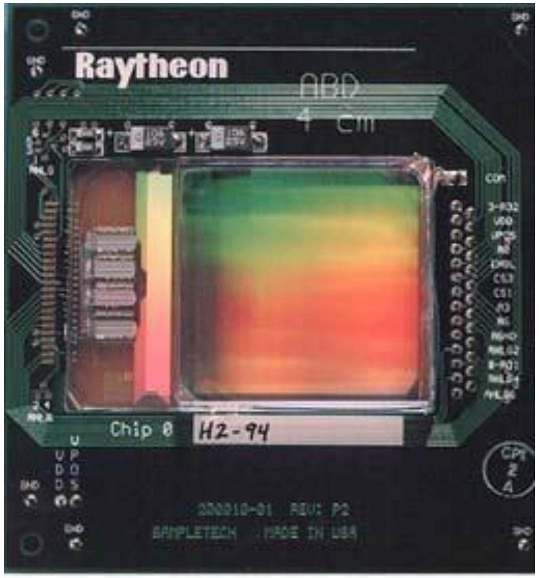
Commercial Ultrafast Lasers for Materials Processing



High Speed Scanning Technologies







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

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

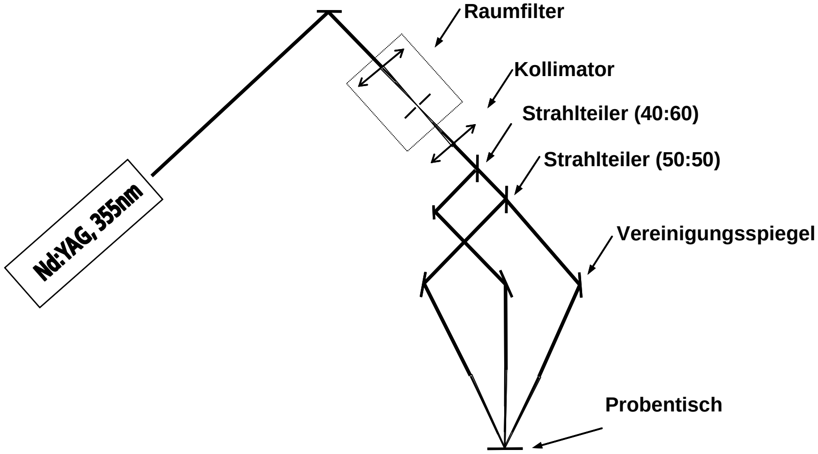
Phased array deflectors
Single line scanning
Scanning angles >20°
Scanning speed >500 m/s for EO-devices

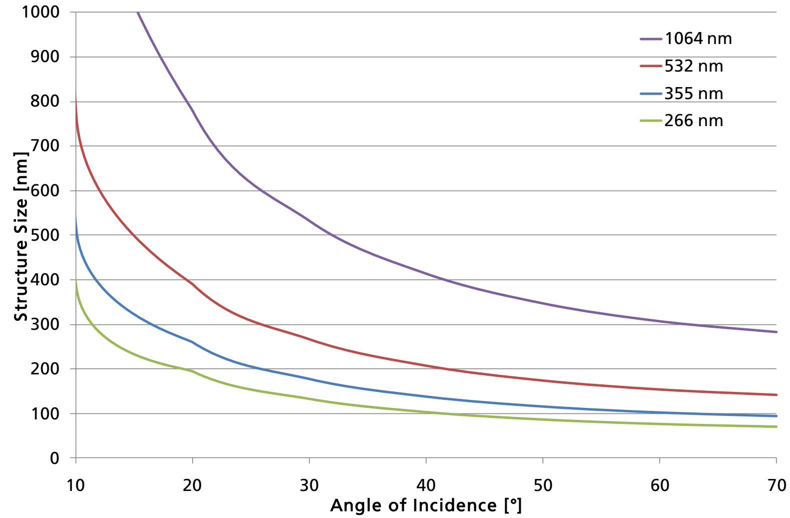
Requirement from ultrafast laser machining @ f = 50 MHz and d_{spot} = 20 µm

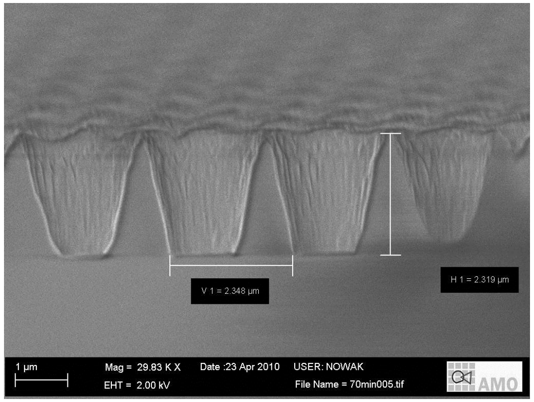
→ **Scanning speed v = 500-1000 m/s**

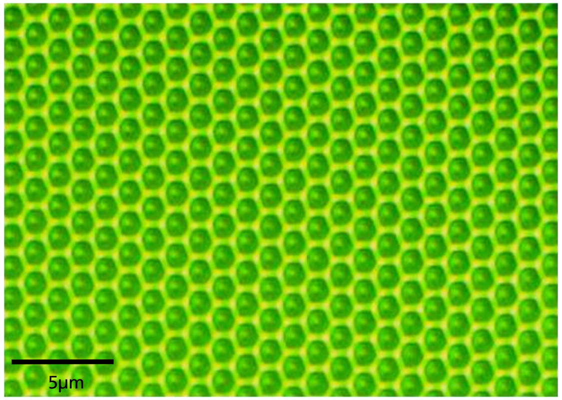
Interferometric Processing

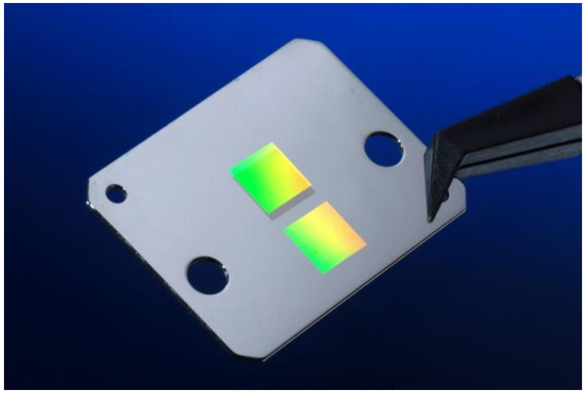
Periodic Nano Structuring
Interference Technique



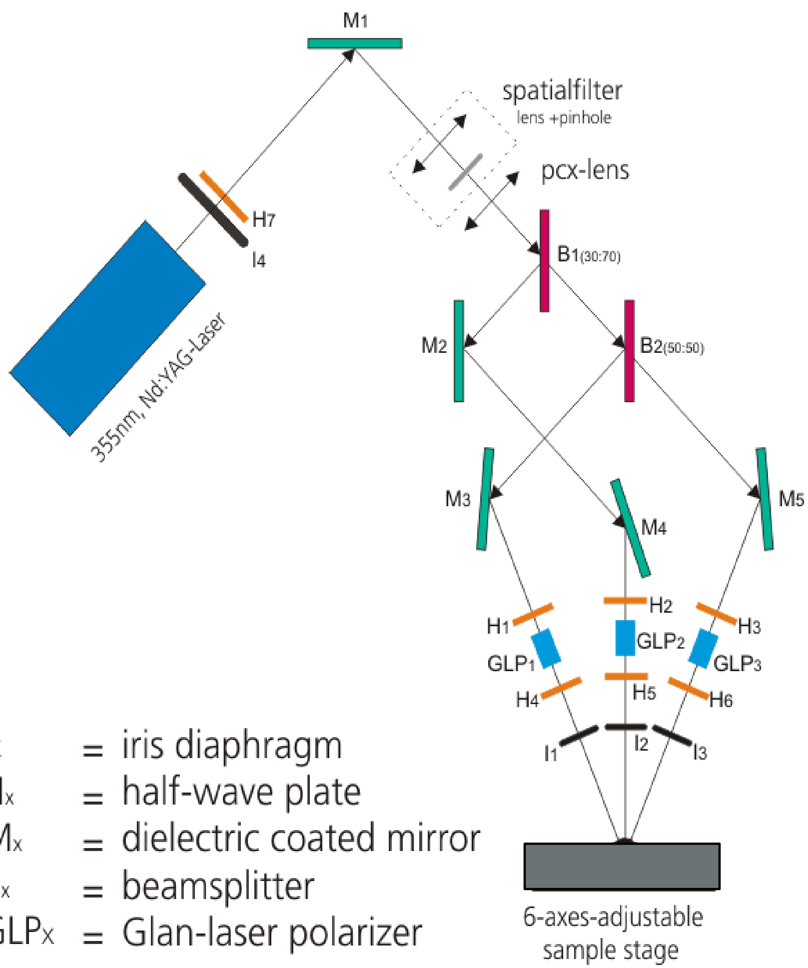




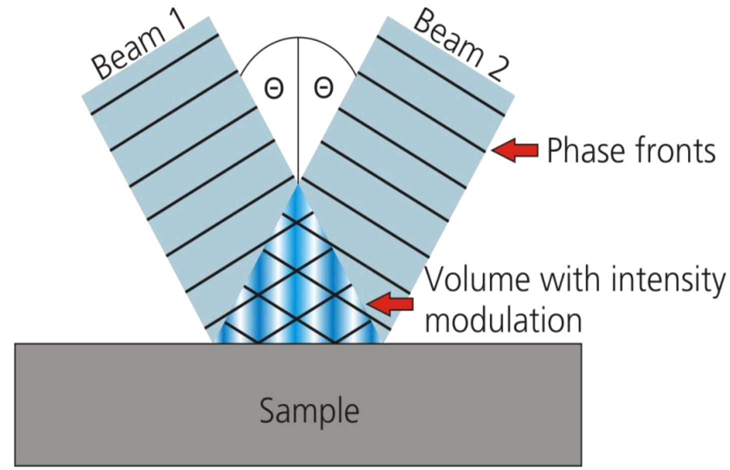


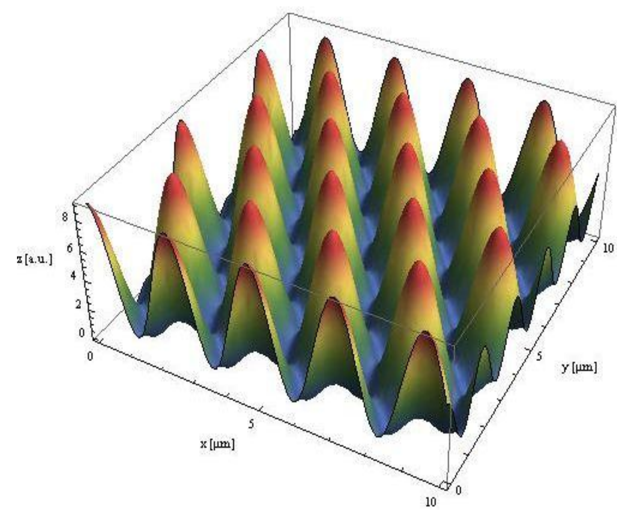


Periodic Nano Structuring
Interference Technique



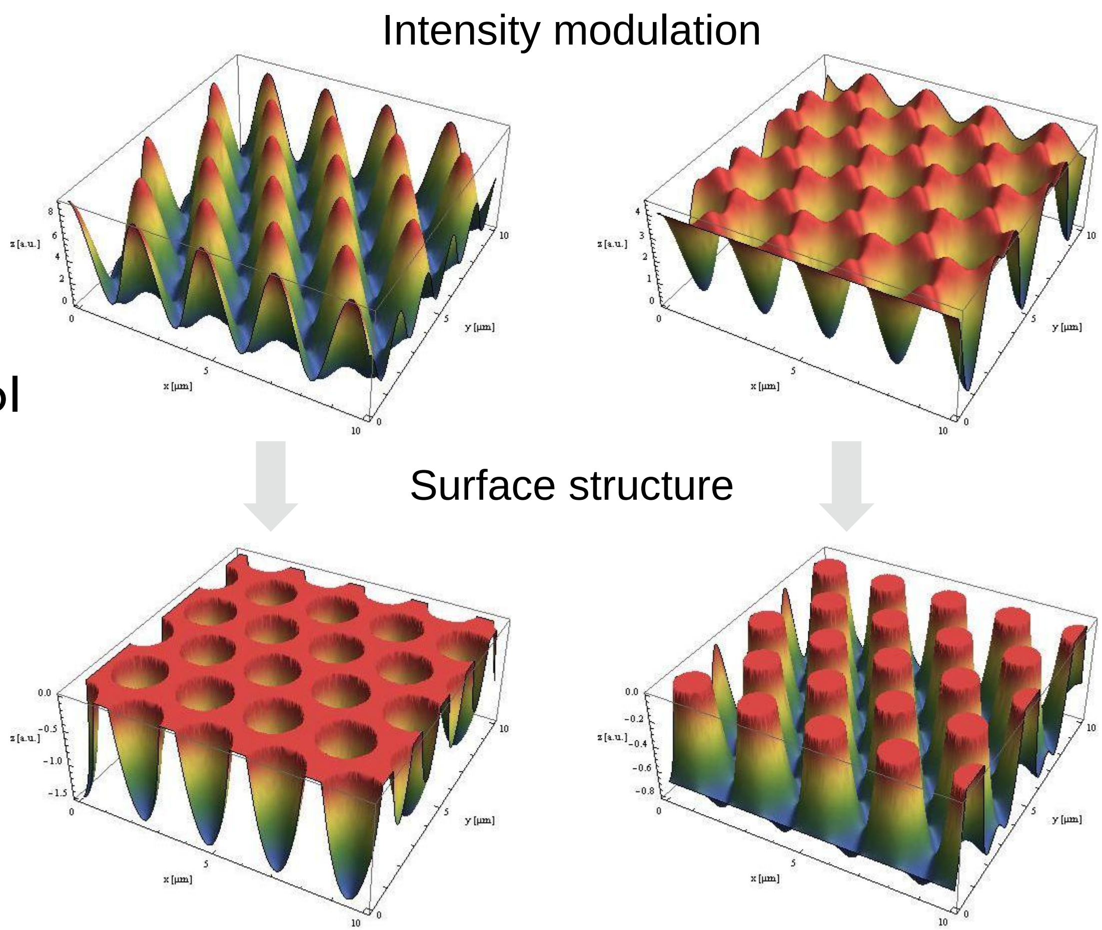
Ix	=	iris diaphragm
Hx	=	half-wave plate
Mx	=	dielectric coated mirror
Bx	=	beamsplitter
GLPx	=	Glan-laser polarizer





Periodic Nano Structuring
Interference Technique

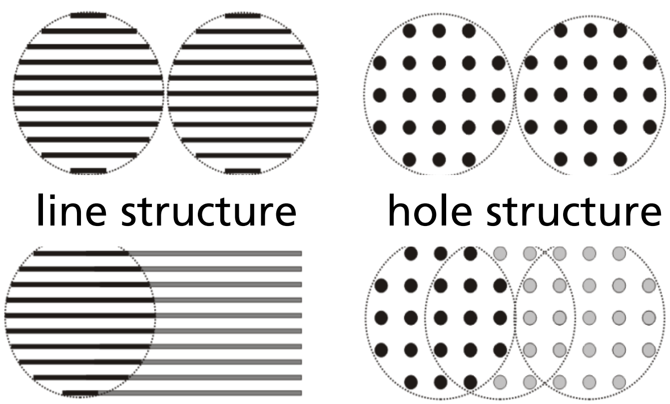
- Intensity distribution depends on
  - Beam configuration e.g. hexagonal mesh for 3-beam set-up
  - Polarisation to control intensity distribution inside a unit cell
  - Amplitude
  - Phase



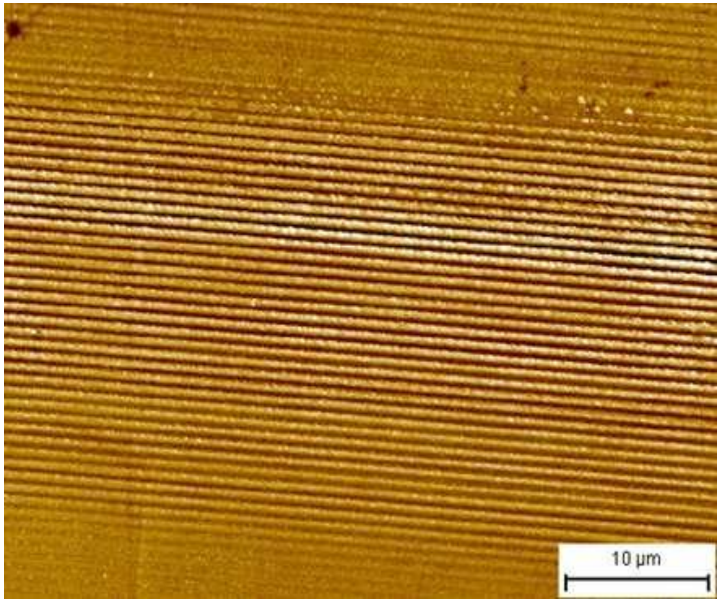
Periodic Nano Structuring
Interference Technique

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

„Spot-für-Spot"-Bearbeitung



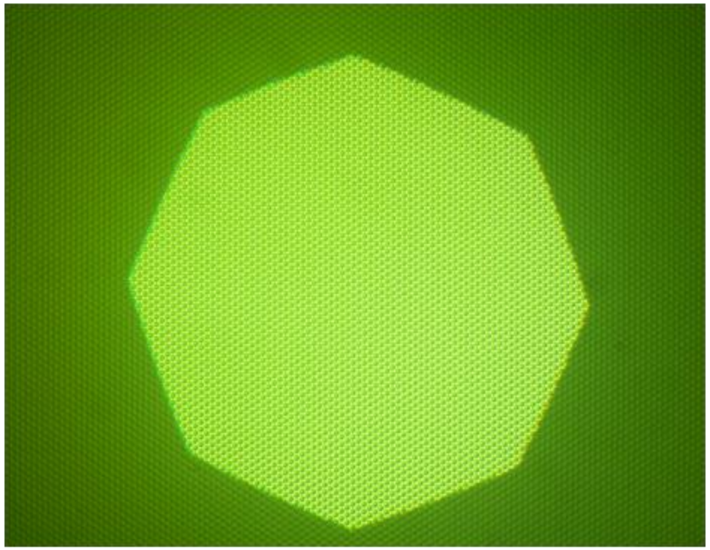
Bearbeitung mit einem Pulsüberlappansatz

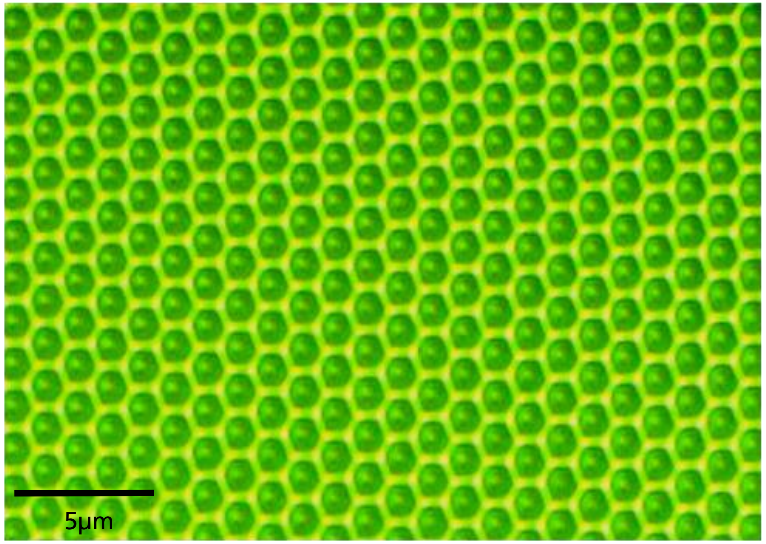


Periodic Nano Structuring

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)

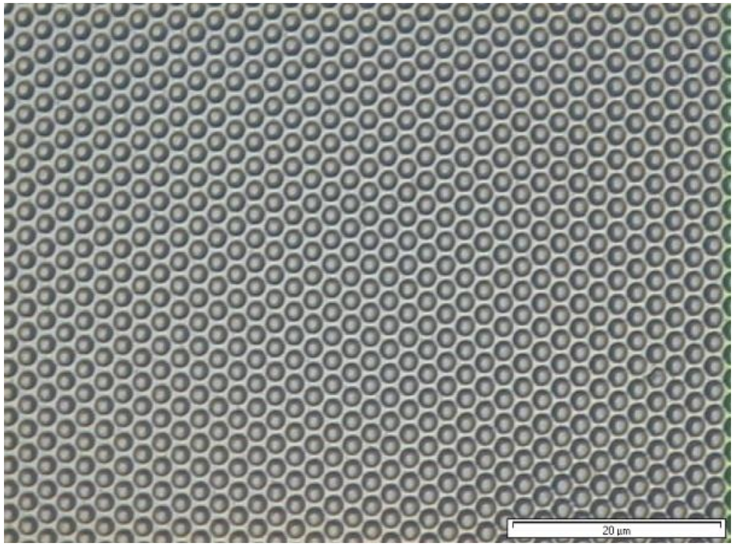


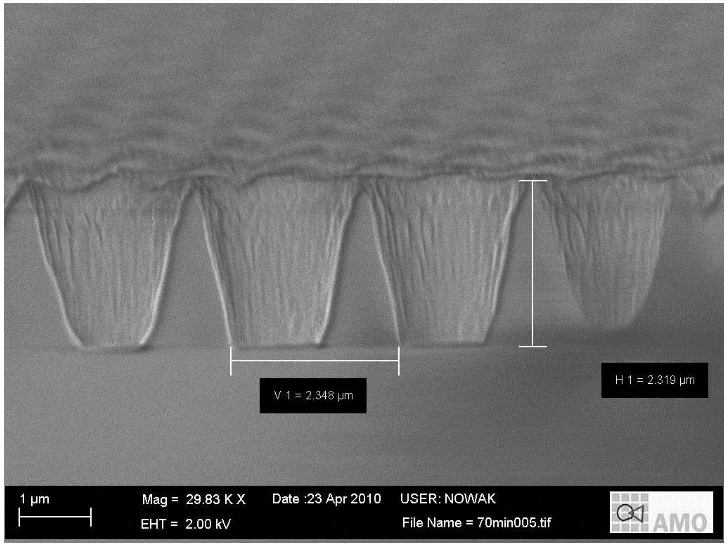


Periodic Nano Structuring

Multi-Beam Interference

- Structure geometry: Ø1.6 µm; Depth: 2.3 µm
- Material: **Quartz glass**
- Structuring into Photoresist
- Subsequent Reactiv Ion Etching



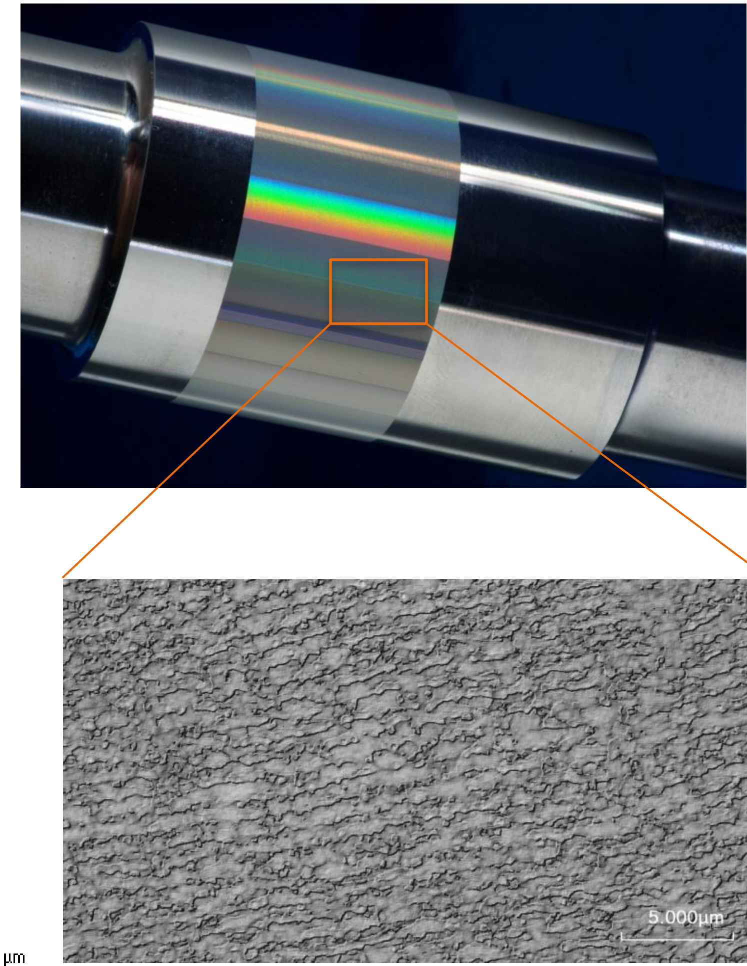


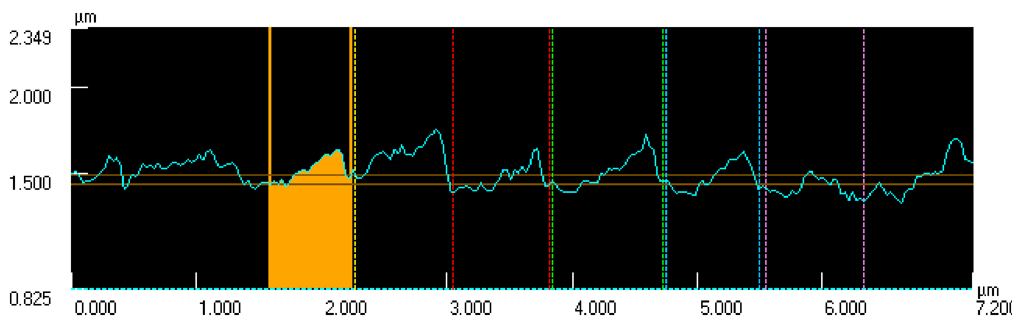
System Technology: Scanning

Replication of Micro and Nano Structures

Embossing Roll Manufacturing

- The embossing roll is made of hardened steel
- The structures are generated by direct laser ablation (1064 nm; 10 ps)
- The structures are 800 nm wide and 300 nm high





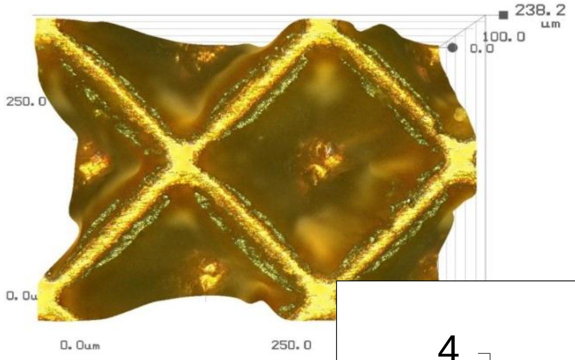
Micro Structured Embossing Rolls

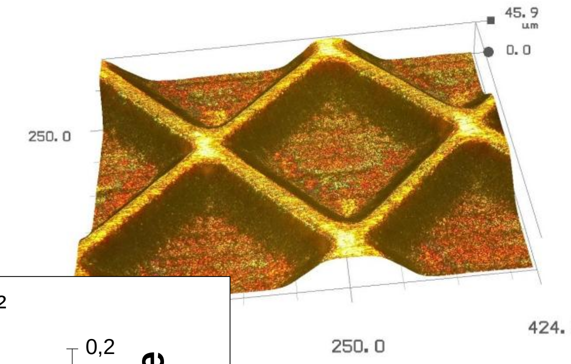
- Material: chrome-plated Copper
- Dimensions:
  Ø250 mm; length 1 m
- Rotational speed:
  1400 rpm (v = 15 m/s)
- Line distance: 2 µm
- Focus diameter: 10 µm
- Laser power: 100 W

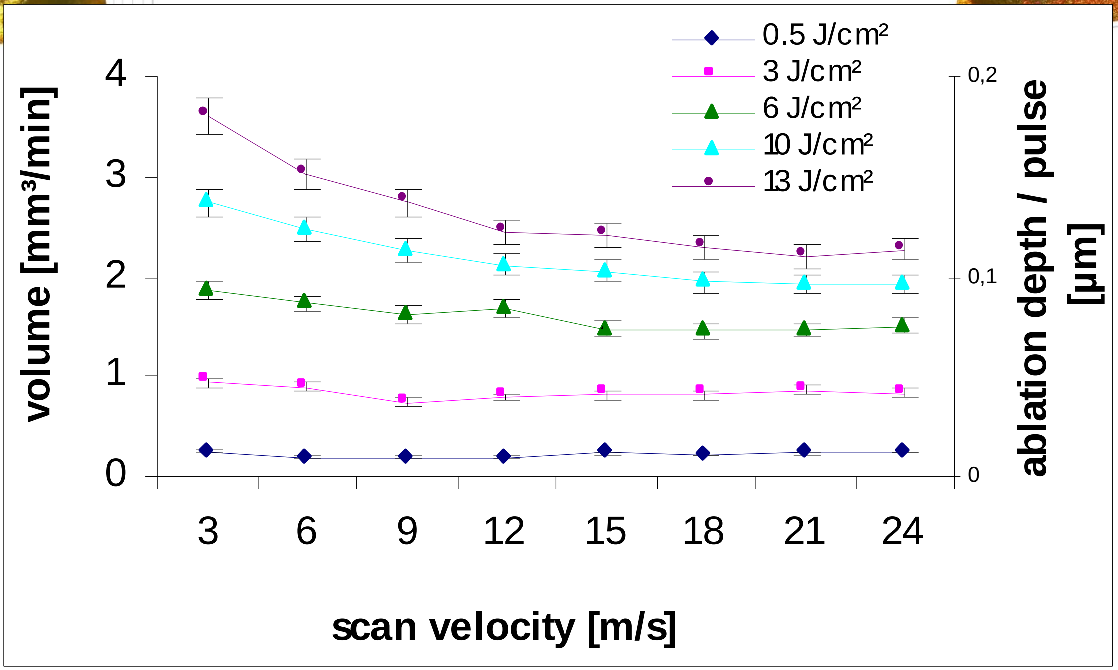
- Surface roughness <0.5 µm
- Min. structure size: 5 µm
- No burr

Large Area Processing

Micro Structured Embossing Rolls







- high pulse overlap
- high pre-heating effect
- melting

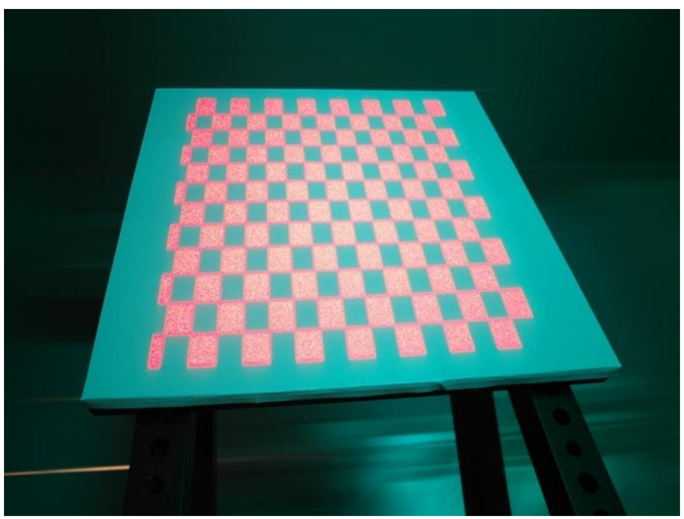
- small pulse overlap
- small pre-heating effect
- only little melting

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

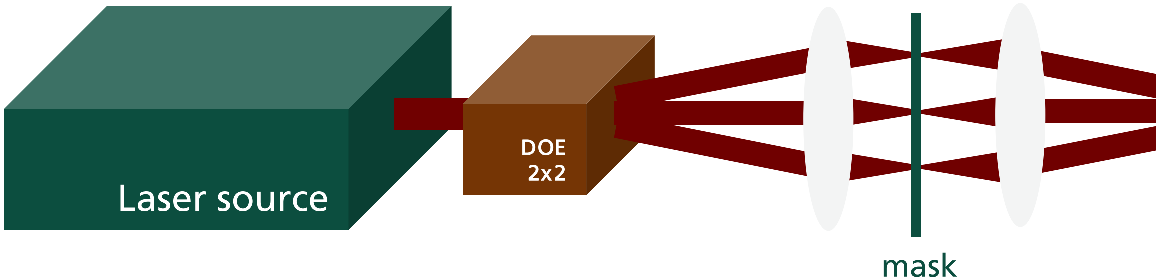
Large Area Processing
Polygonic Mirror

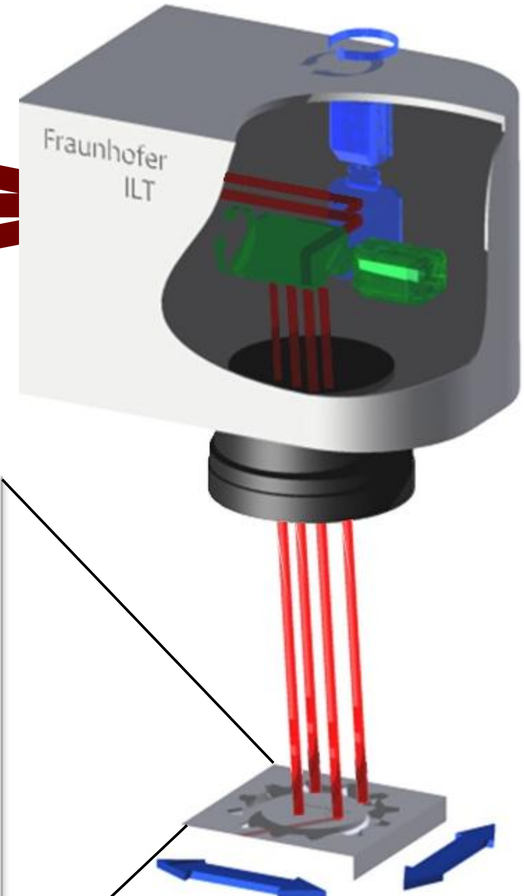
- **Chess pattern**
  - Calculation on FPGA
  - 40 MHz Output Frequency
  - Feed rate: 35 mm/s
  - 9500 rpm



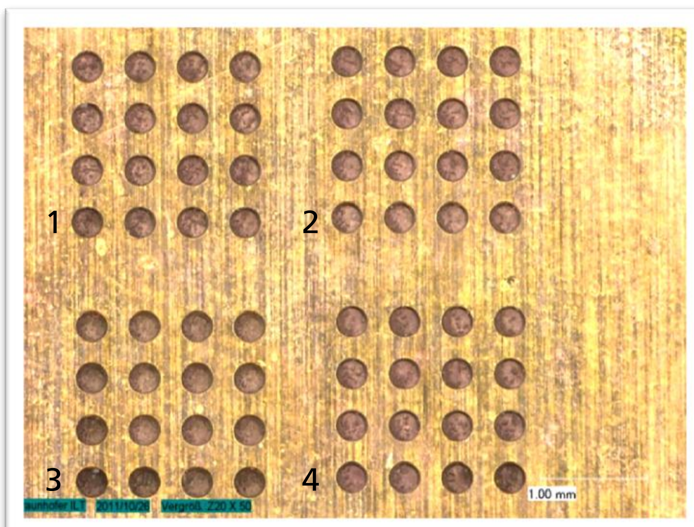
AC Dom, ILT + Polyscan Logo
- PNG-Import (25 MPix)
- 10 MHz Output Frequency
- Feed rate: 18 mm/s
- 2800 rpm

Large Area Processing
Multi-Beam Laser Processing with DOEs





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



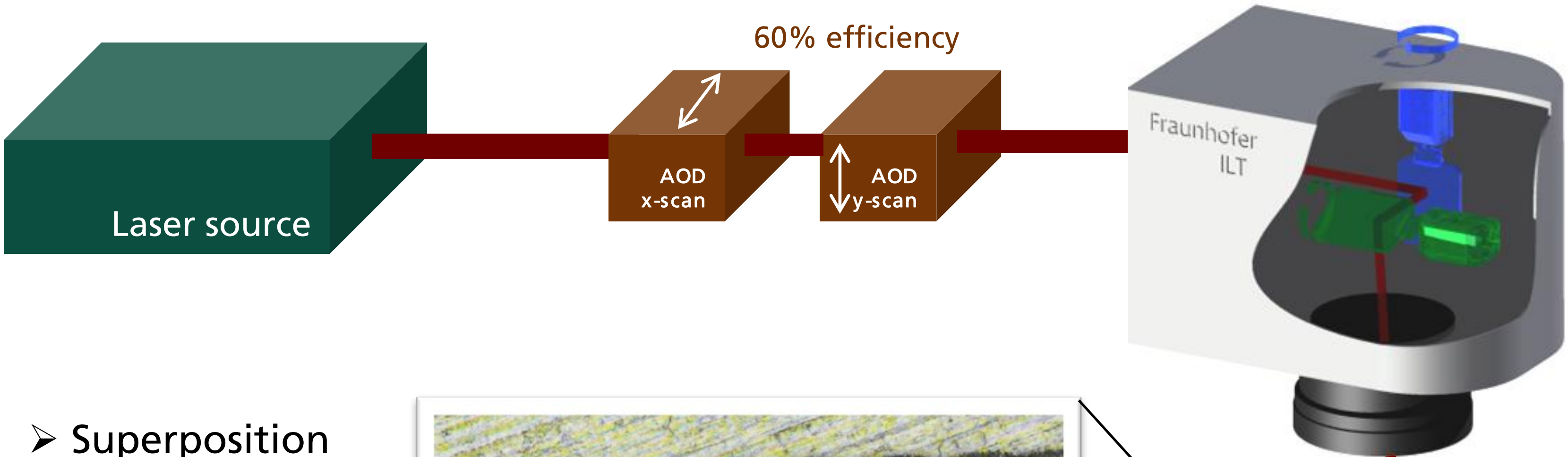
DOE: Diffractive Optical Element

Large Area Processing

Multi-Beam Laser Processing with DOEs

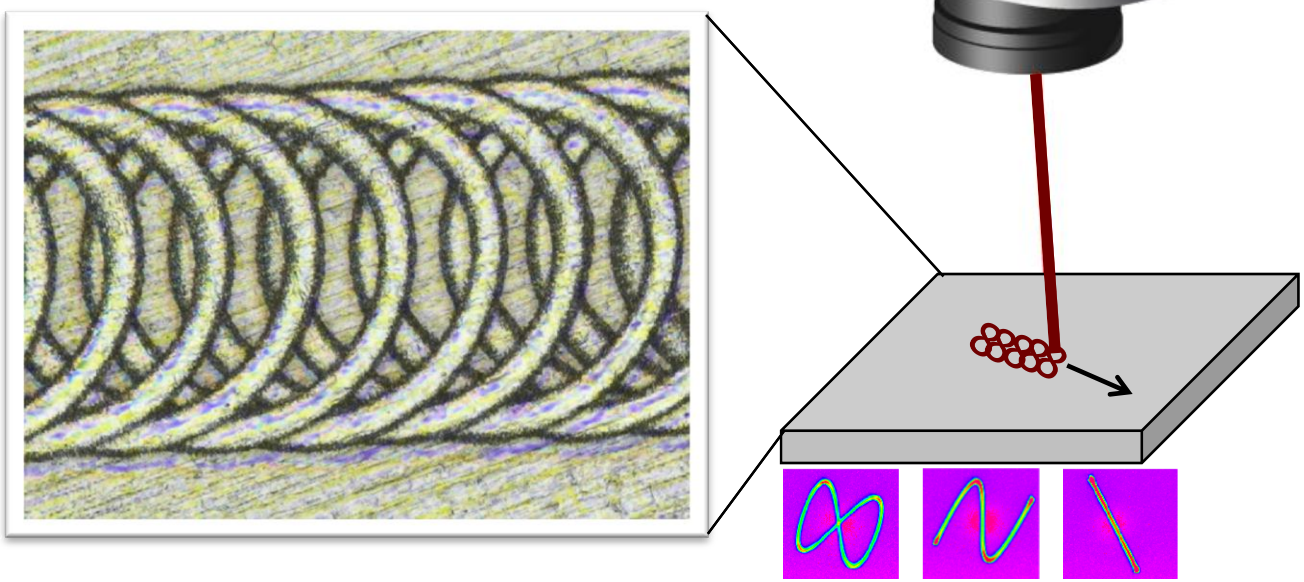
Large Area Processing

Hybrid Scanner: Acousto-Optic Deflector & Galvanometer Scanner



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

- Scan velocity up to 120m/s



Future Developments

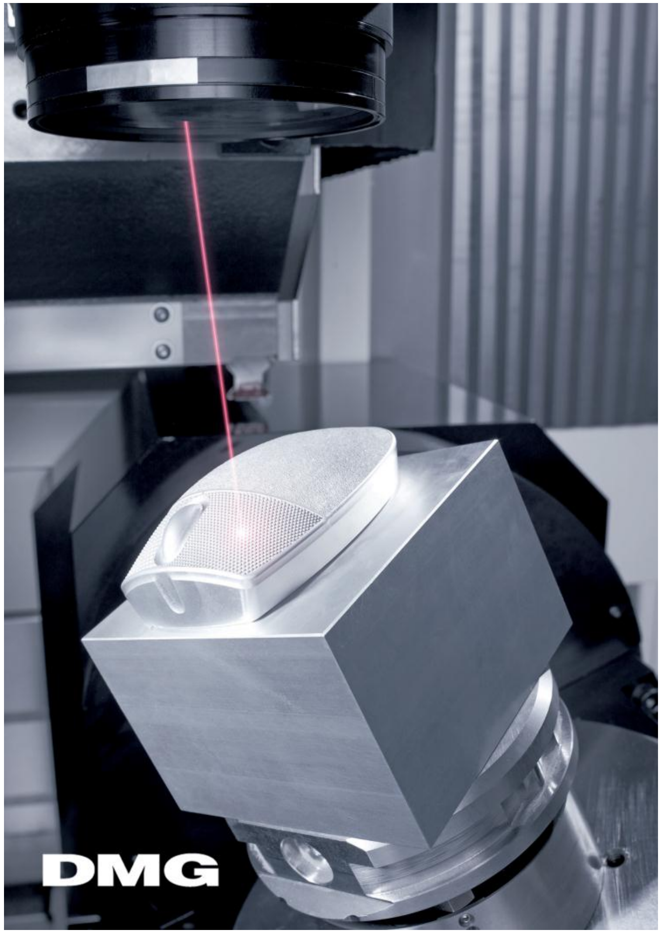
Ultrafast Manufacturing

Today:

- Typical ablation rates of e.g. Aluminum ca. 0,1 mm^3/sec
- Limited by max. laser power and scanning speed

Future potential:

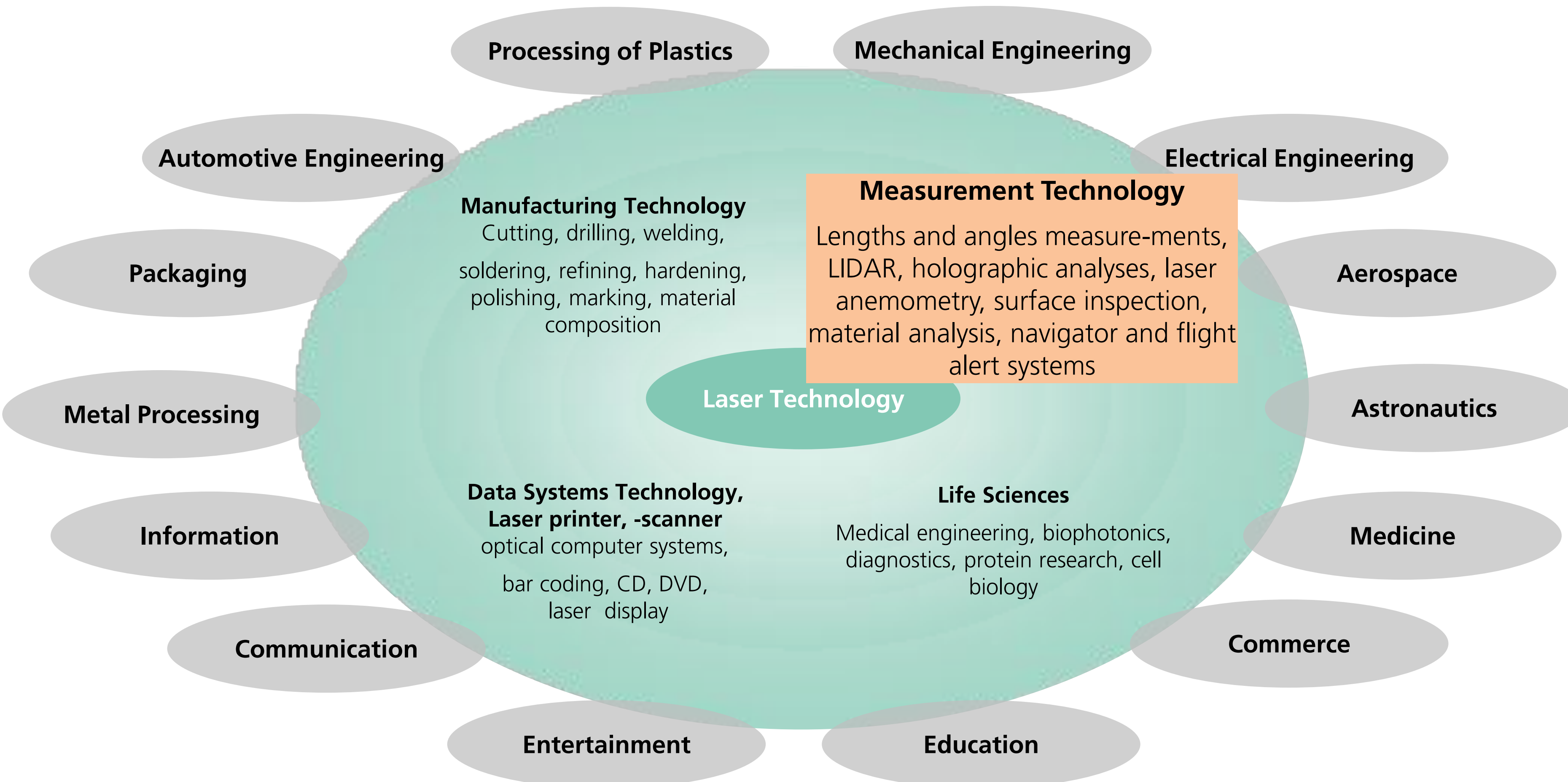
- Ablation rates of >**5 mm^3/sec = 20 cm^3/h**
- Use of fast deflection systems and >1 kW average Power
- Direct manufacturing of small components e.g. with specific surface features



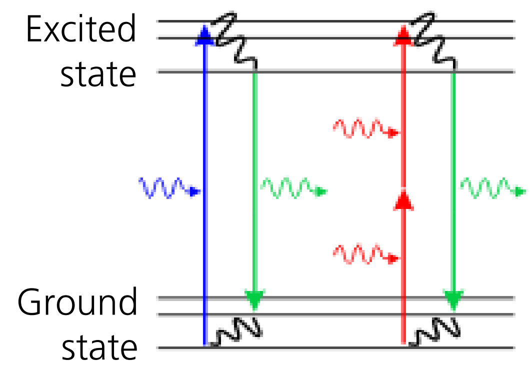
Process Characteristics

- Average Power: > **1 kW** (ILT still world record)
- Repetition Rate: typ. **10 MHz**
- Pulse Energy: **100 µJ** (@ 1 ps)
- Pulse Power: **100 MW**
- Intensity: 100 TW/cm^2 = **10^{14} W/cm^2** @ $(10\ \mu m)^2$
- Penetration depth: dep. on material, app. **100 nm @ 1 ps**
- Energy density: **10^7 J/cm^3** (Vap. enthalpy metal < 10^5 J/cm^3)
- Ablation Rate: **5-10 mm^3/s**

Application Markets



Example Measurement Technology: Two Photon Microscopy



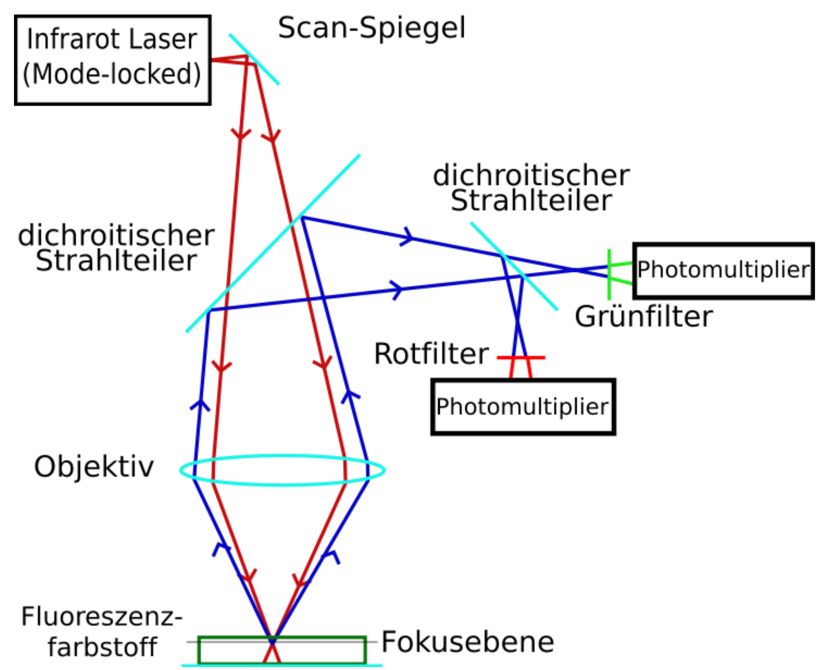
Only in the focus there is sufficient intensity for **simultaneous absorption of two Photons**

Femtosecond Lasrers provide the intensity

Probability for two "simultaneous" Photons **$\sim I^2$**
→ small excitation volumen

Resolution ~300 nm radial and ~500 nm axial (for Infrared 800 nm)

High penetration depth of infrared (up to 1 mm in organic tissue)

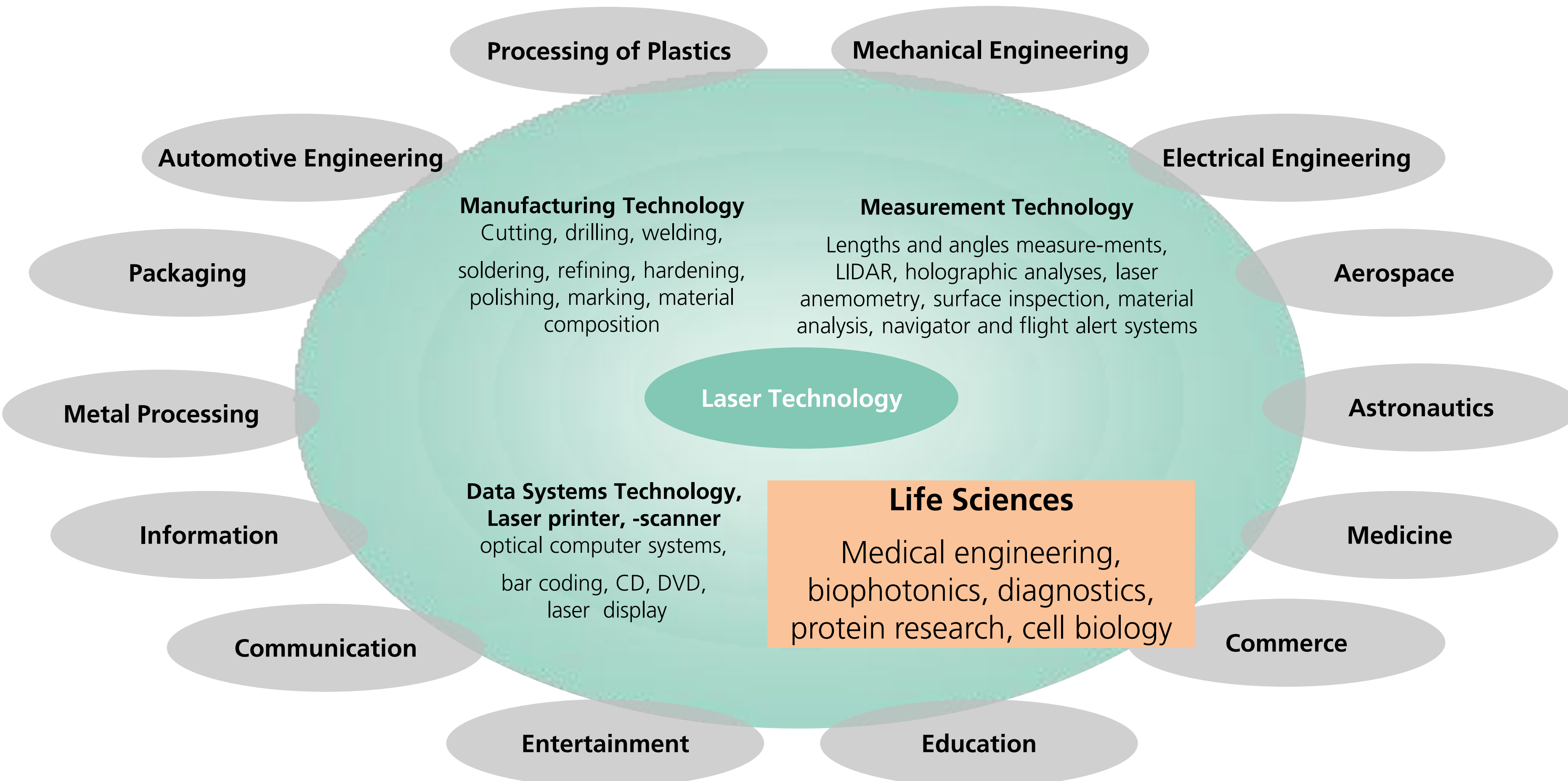


Example Measurement Technology: Two Photon Microscopy

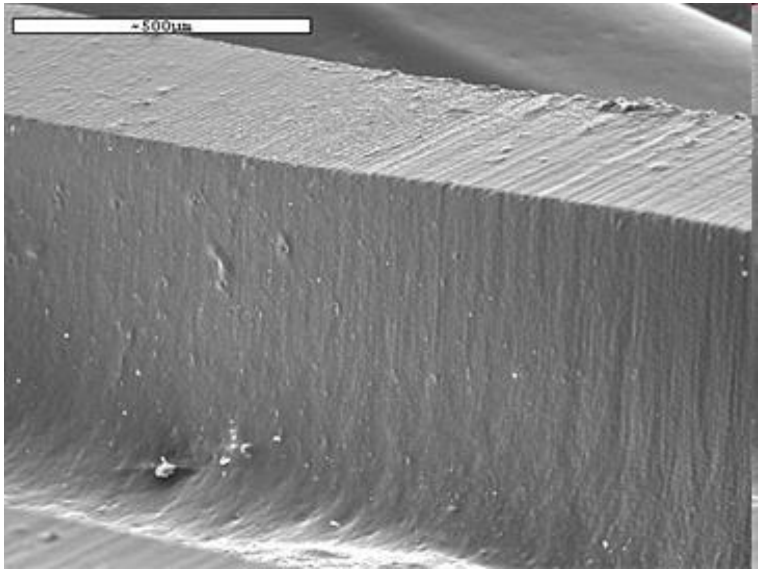
Laser-Raster-
microskope

Two-Photon-
Microskope

Application Markets



Example Life Science:
Tooth *in vitro*



„Precision Meets Ablation Rate with Macroscopic Relevance“

sirona The Dental Company

LUMERA LASER

RWTH RHEINISCH-WESTFÄLISCHE TECHNISCHE HOCHSCHULE AACHEN LLT LEHRSTUHL FÜR LASERTECHNIK

Fraunhofer ILT

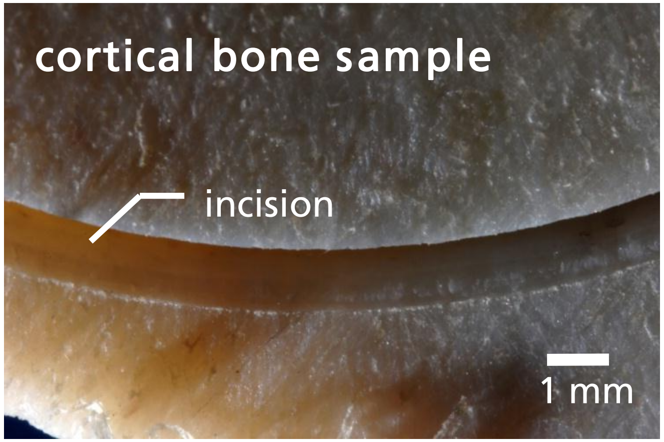
Short pulsed bone tissue ablation

ps-laser

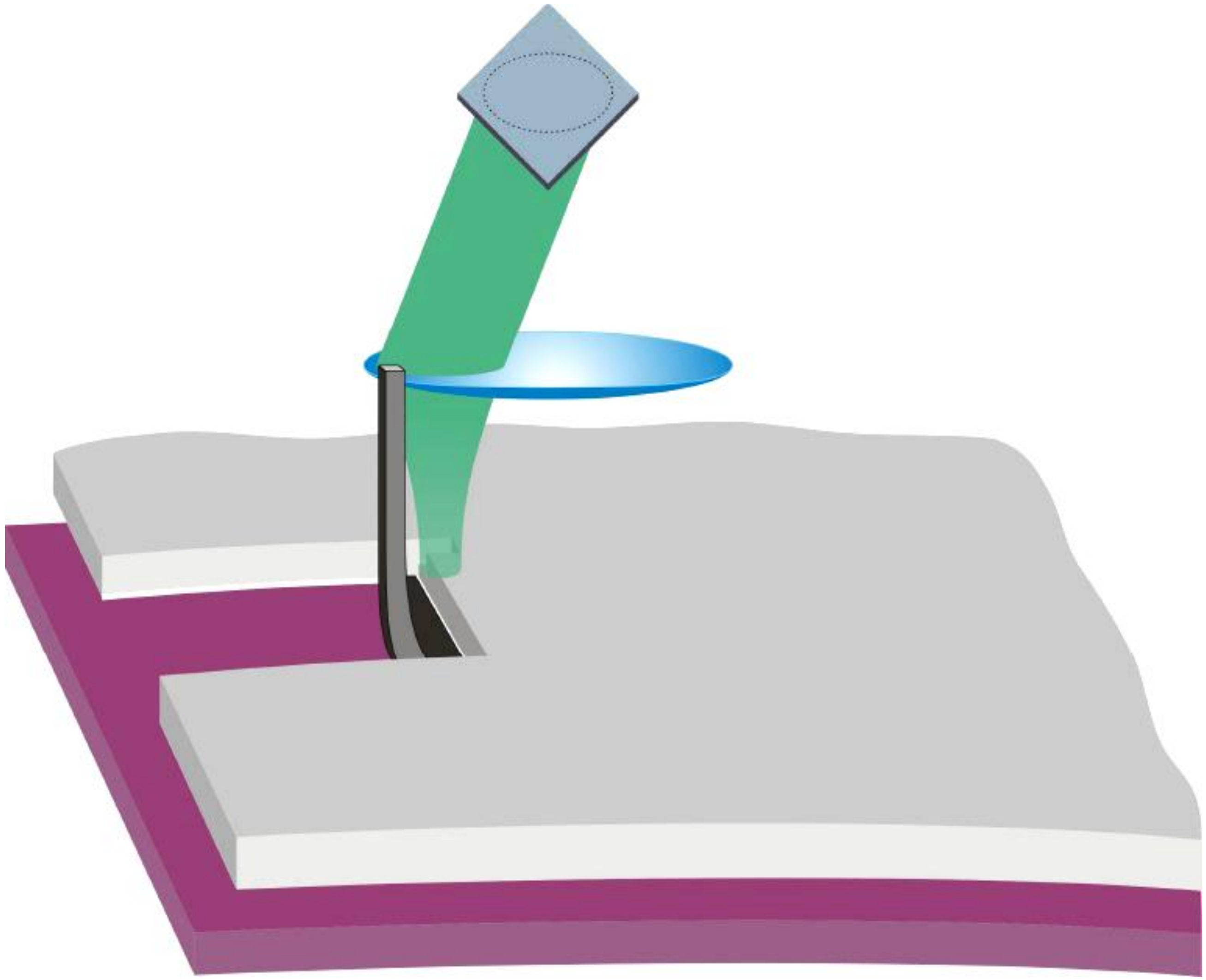
- $Nd{:}YVO_4$, τ_p = 25 ps
- P_{max} = 20 W @ λ = 532 nm
- f_{rep} = 20 kHz
- w_0 = 16 µm → $I = 5 \cdot 10^{12}$ W/cm²
- Scan speed v_{sc} = 4 m/s (fast axis)

incision in bovine femur

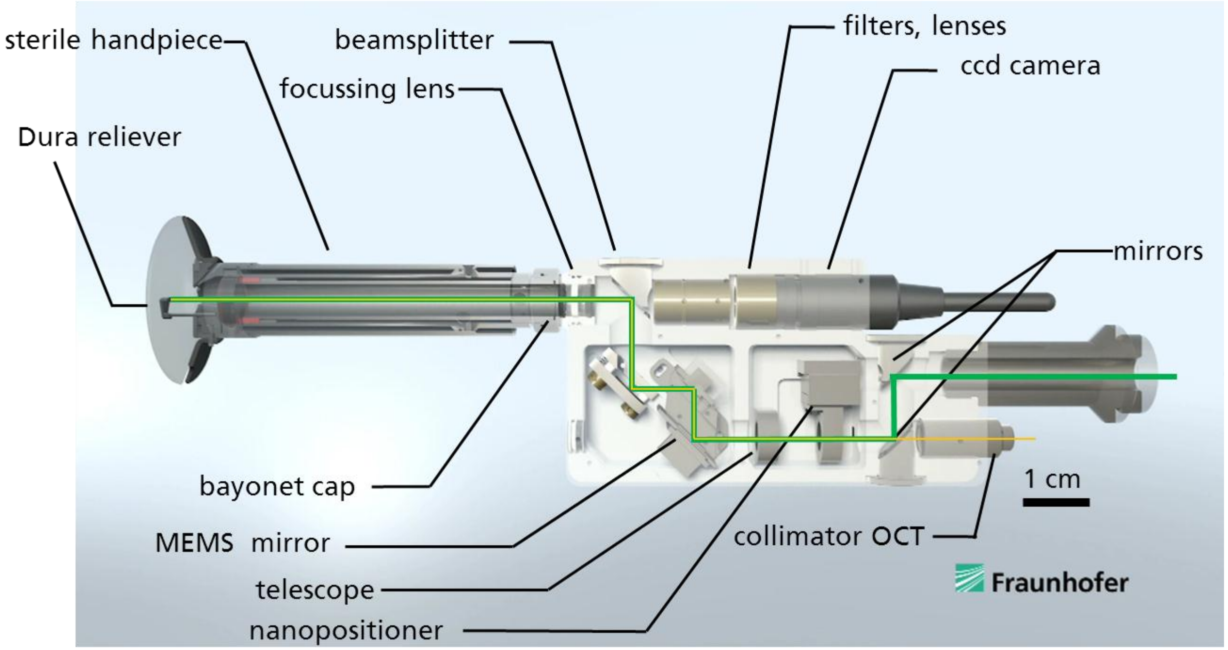
- width B > 0,5 mm
- length 2 mm < L < 8 mm
- aspect ratio depth : width = 5
- ablation rate dV/dt = 0,2 mm³/s



Prototype for hand-guided osteotomy

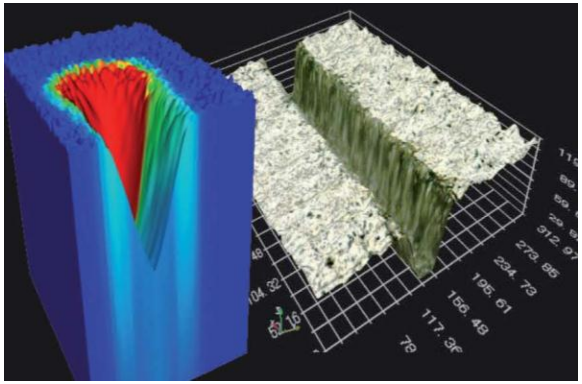


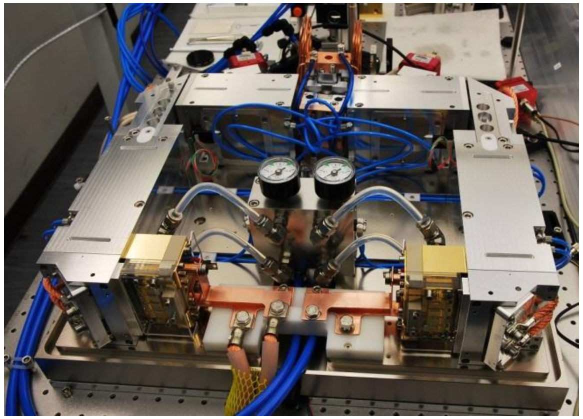
Prototype for hand-guided osteotomy



Summary of Future Tends

- Digital Photonic Production is widely developing
- Ultrafast High Precision Machining is presently the fastest growing Laser Application Market
- Need for Process development/ strategy, especially System Development
- Diode Laser Technology will decide global leadership






SAVE THE DATE
LASER APPLICATIONS
OF TOMORROW
MAY 7 - 9, 2014
IN AACHEN
AKL'14
INTERNATIONAL LASER
TECHNOLOGY CONGRESS
Fraunhofer Institute for Laser Technology ILT
www.lasercongress.org

Questions?

End of presentation

Thank you very much for your Attention