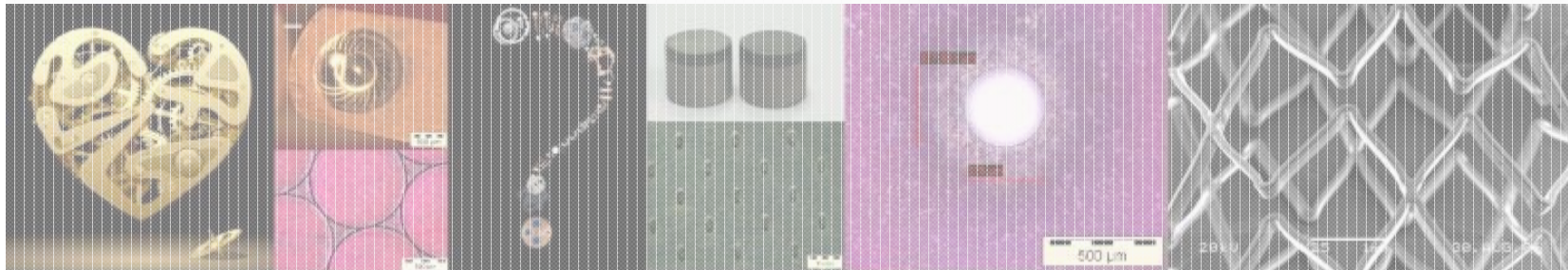




## Industrial applications with ultra-fast lasers - status quo?

Ronald Holtz, Beat Lüscher, Armin Stumpp, Florian Senn, Jörn Lungershausen (Fachhochschule Nordwestschweiz)  
Reiner Witte, Noémie Dury (Class 4 Laser Professionals AG)

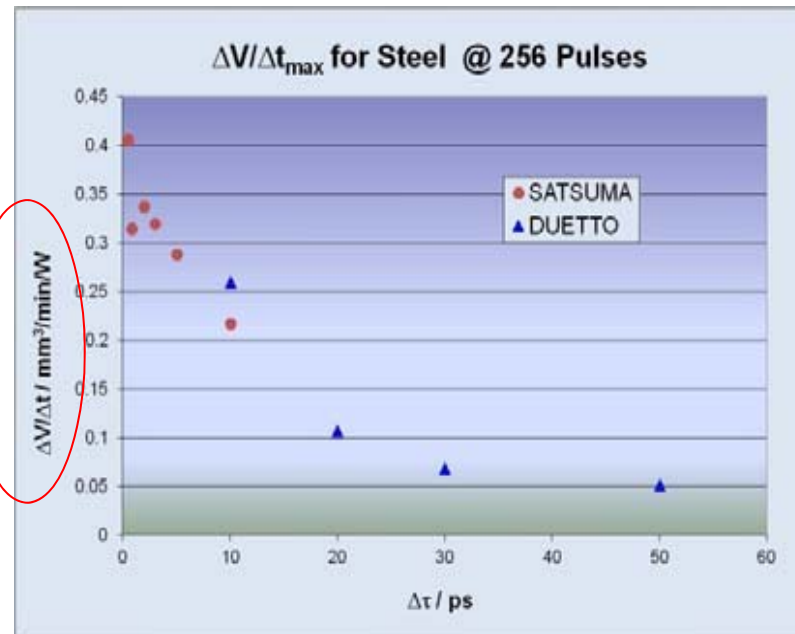
- Introduction
- Approach: Market development
- Approach: Direct machining - Competition
- Approach: Replication



**Process related approach** vs. **Cost related approach** → **Solution?**

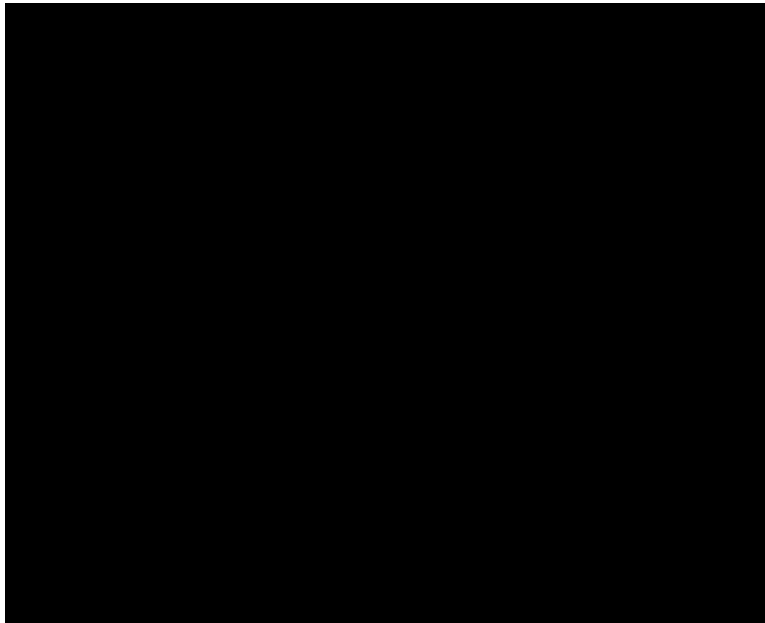
$\Delta V/\Delta t/\text{mm}^3/\text{min}/\text{W}$

$\Delta V/\Delta t/\text{mm}^3/\text{min}/\text{€}$



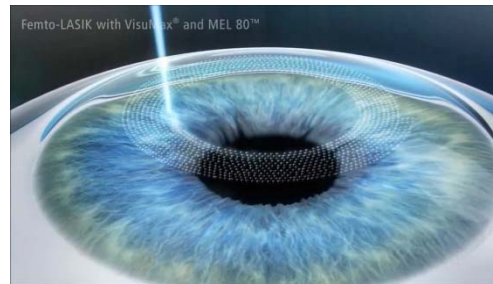
Neuenschwander et. al.: From ps to fs...

Approach 1: Market development



Apple 2012

**LASIK**

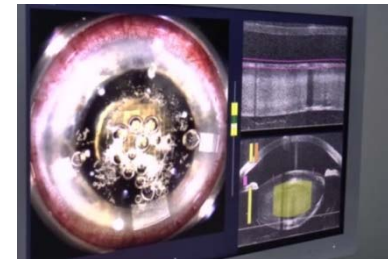


Zeiss

**Presbyopia**



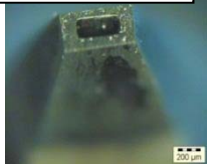

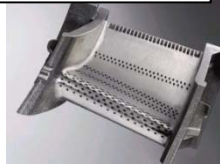

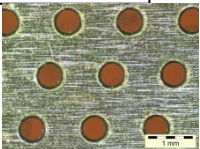
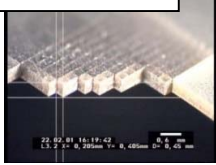
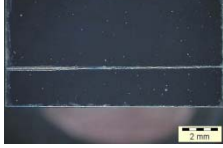

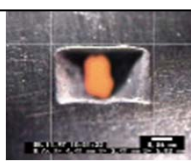

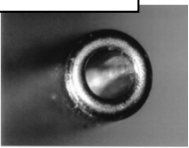
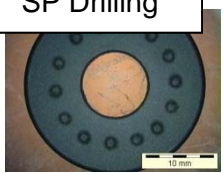
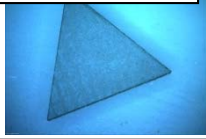

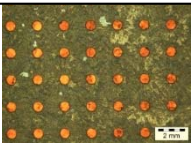

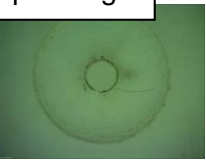
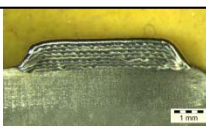




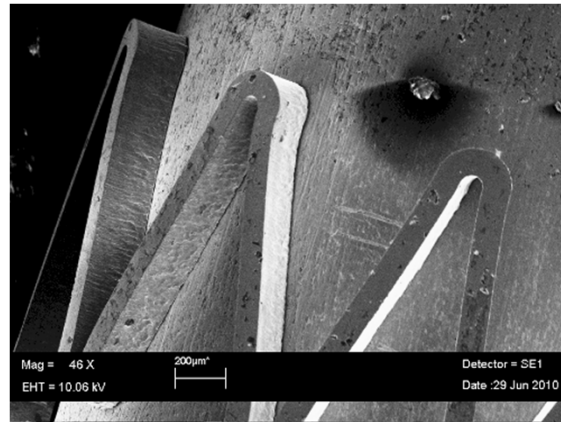
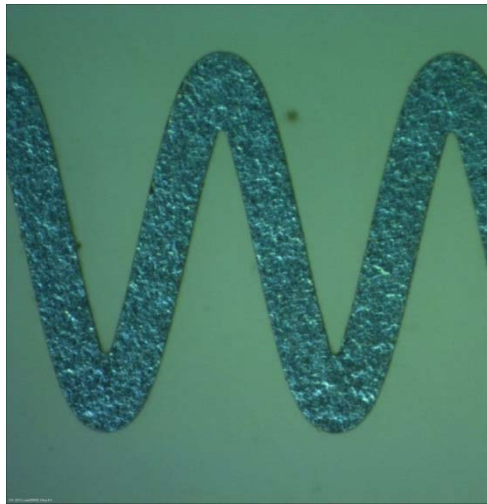
**Cataract**



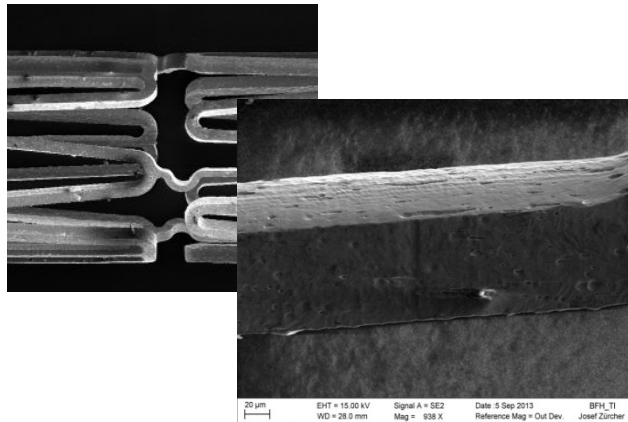
LenSx Alcon

Approach 2: Direct machining - competing with conventional laser processing

Medical Engineering	Electronics	Tool	Automotive	Turbine	Mechanical Devices
cutting 	spot welding 	Shaped holes 	scribing 	Perc. drilling 	Cutting 
OTF drilling 	cutting 	Perc. drilling 	OTF drilling 	Shaped holes 	welding 
SP drilling 	SP Drilling 	cutting 	Perc. drilling 	OTF drilling 	OTF drilling 
Trepanning 		Welding 		Welding 	Perc. drilling 



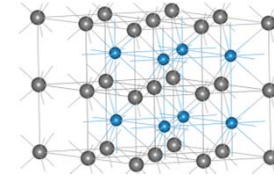
Material: Nitinol 0.2 mm  
 Laser: IPG QCW 150 SM  
 Parameter: 0.25 kW Peak  
 power, 0.07 ms Pulse  
 length  
 Comments: Ar2, 400 mm/min



Material: Nitinol 0.05 mm, D=0.3 mm  
 Laser: Jenoptik D2.fs  
 Comments: Ar2, 200 mm/min

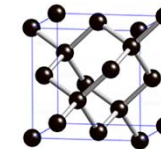
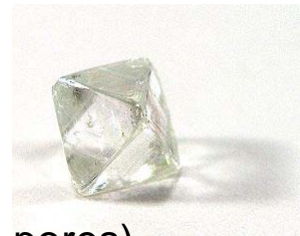
## PCD material

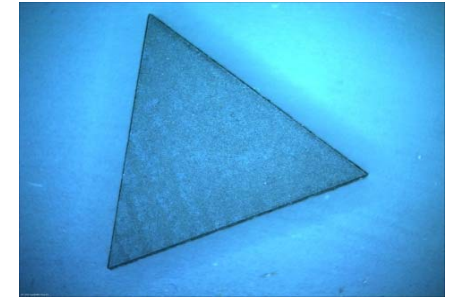
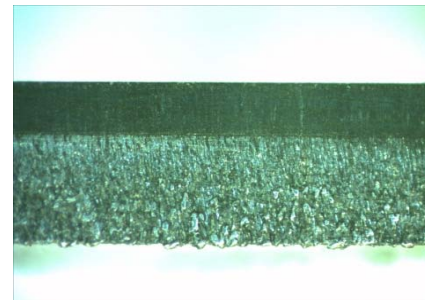
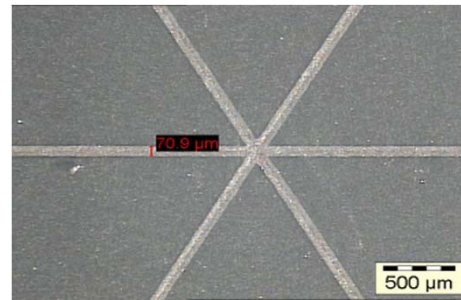
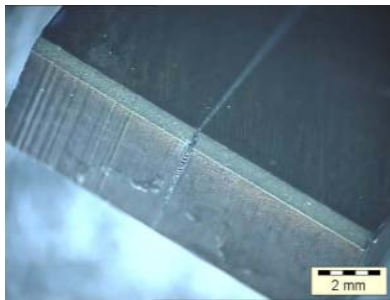
- High melting point of tungsten carbide (2870 °C)
- Low graphitisation temperature of Diamond (650 - 800 °C)
- Interface tensions between carbide and diamond



## Single Crystal

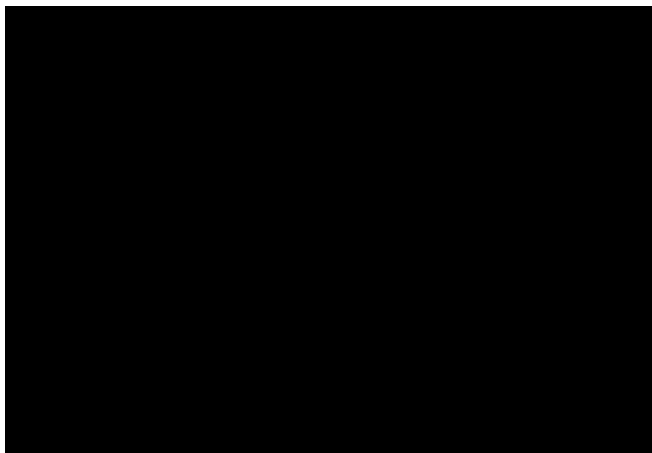
- High melting point (3550 °C)
- Low graphitisation temperature
- No homogenous material (inclusions, pores)
- Crystallographic directions (tensions, absorption)
- Risk of local overheating due to prohibited thermal flow





CBN	SLAB Laser	QCW 150 SM
1.6 mm	30 mm/min	60 mm/min
2.1 mm	12 mm/min	12 mm/min
3.2 mm	5 mm/min	x

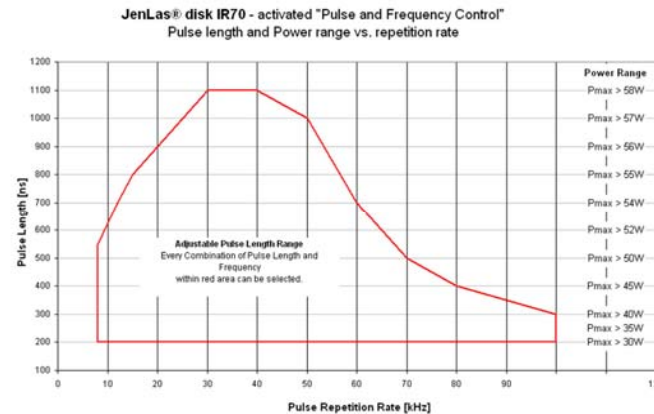
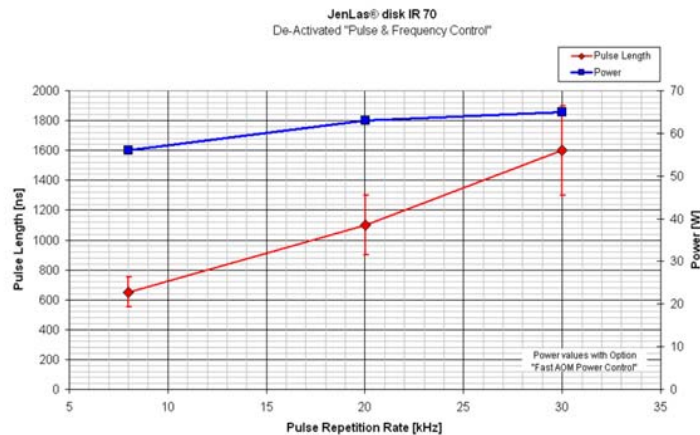
PCD	FLS 352N	QCW 150 SM	IPG YLS-600-QCW
1.6 mm	120 mm/min	80 mm/min	160 mm/min
2.1 mm	80 mm/min	15 mm/min	100 mm/min
3.2 mm	25 mm/min		40 mm/min



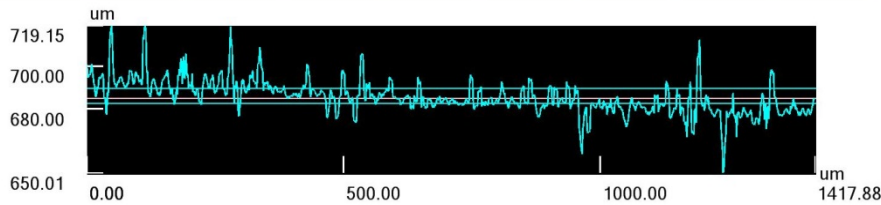
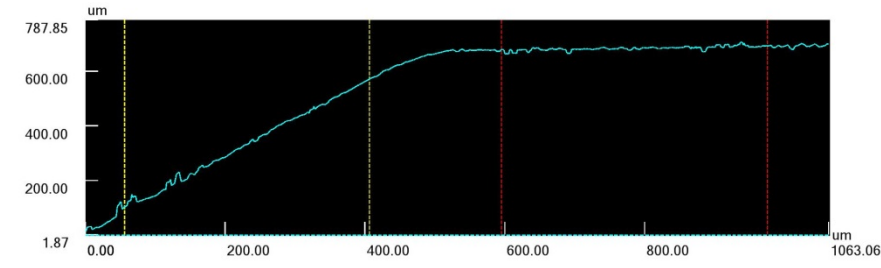
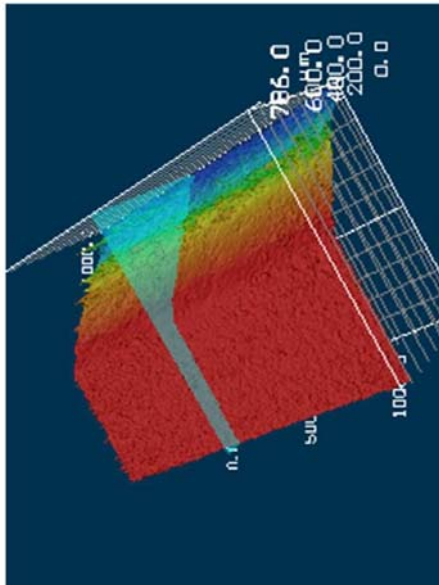
*Material:* CBN 1.6 mm  
*Laser:* C4-150 SM  
*Parameter:* 1.5 kW Peak power,  
 0.1 ms Pulse length  
 35 W Average Power  
*Comments:* N2, 16 bar, 60 mm/min



- Single/ Dual path cutting by high peak power short pulse length pulses
- Low average power process
- Midrange temperature gradients – low risk for stress related cracks
- Low risk of saturation due to low duty cycle – low risk for temperature related cracks
- State of the art q-switch disk laser technology
- Higher product costs comparing to q-switch fiber lasers, same costs like QCW laser



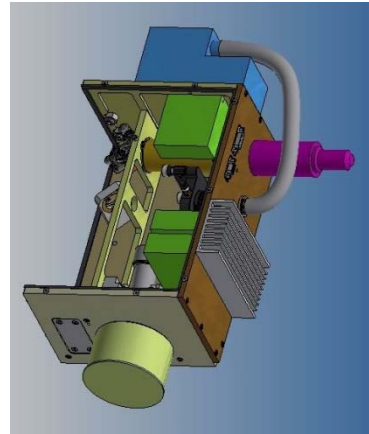
max. pulse energy: 8kHz, 0.6 us  
max. pulse length (1.6 us): 30 kHz, 2 mJ



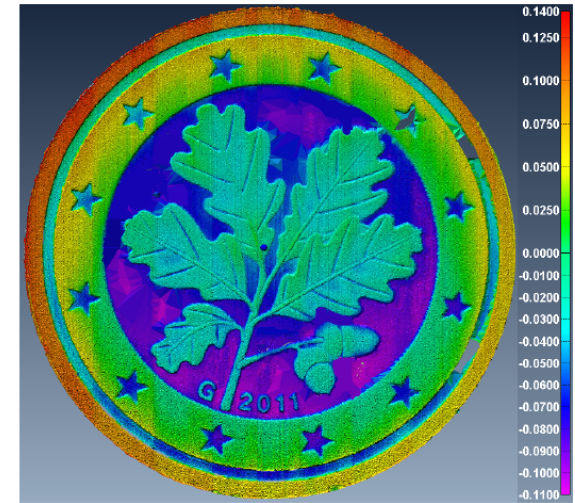
Profile 1	Horz. dist.	Rp	Rv	Rz(Rt)	Rc	Ra
All	1417.88um	33.46um	35.69um	69.15um	45.20um	5.90um
Seg.1						
Seg.2						
Seg.3						

## Dicing and ablating with galvo scanner

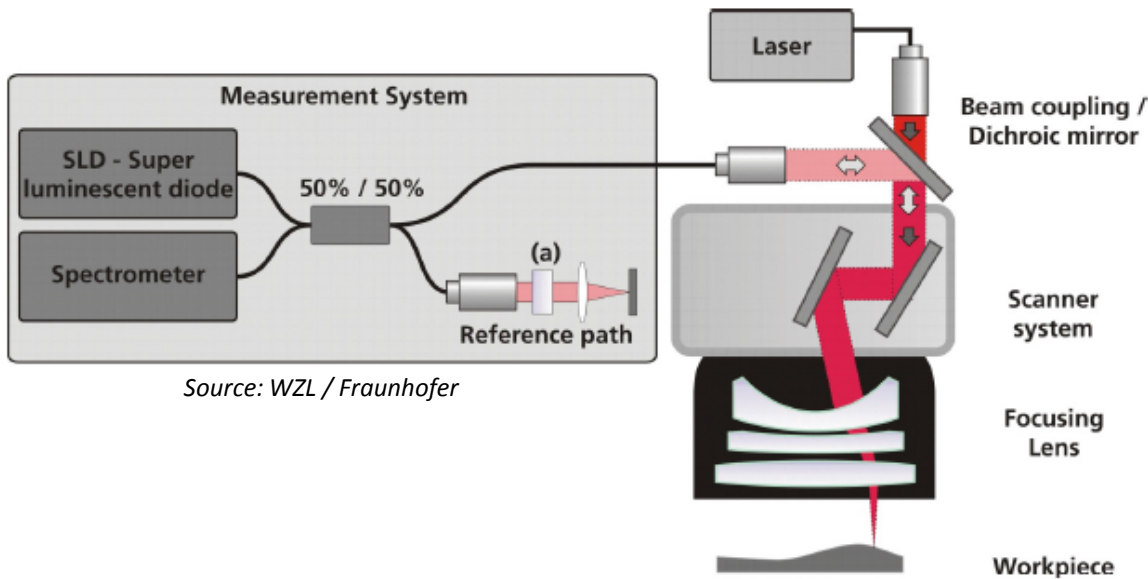
- Dicing with «beam wobbling» layer by layer
- Shaping by beam scanning afterwards
- Dicing with calculated speed of about 30 mm/min (1.6 mm material)
- No post processing – finishing quality



Measurement of a 2 cent euro coin

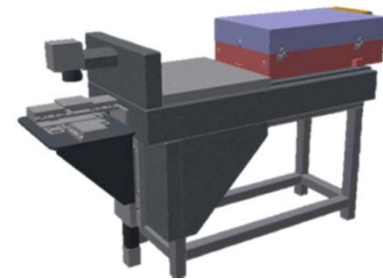


Source: WZL / Fraunhofer

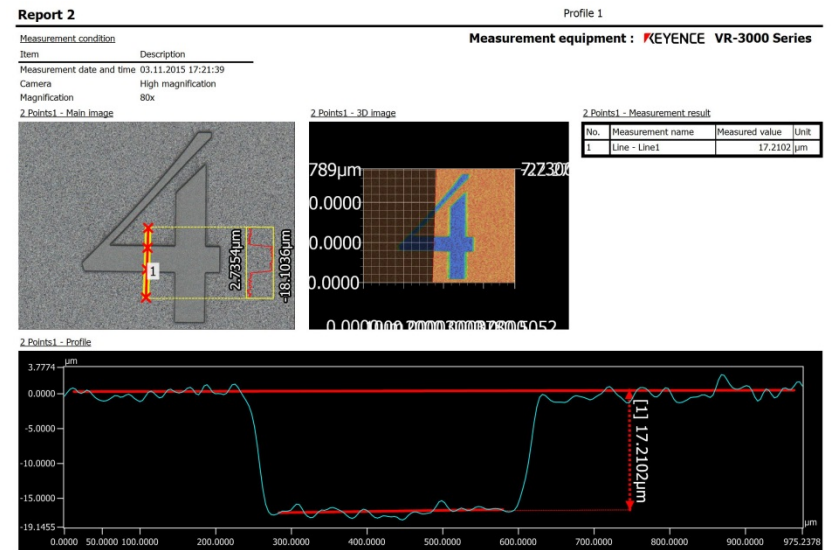


Source: WZL / Fraunhofer

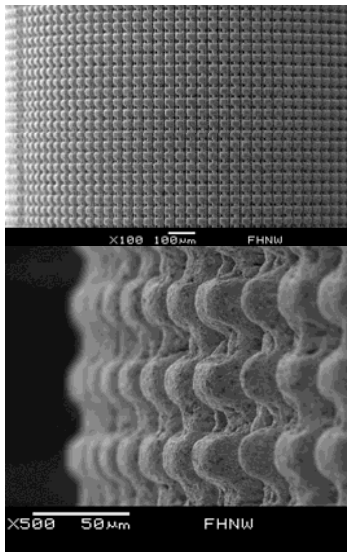
- Measuring range:  $\pm 1.3$  mm
- Measuring system repeatability: 100 nm
- Measuring frequency max. 70 kHz



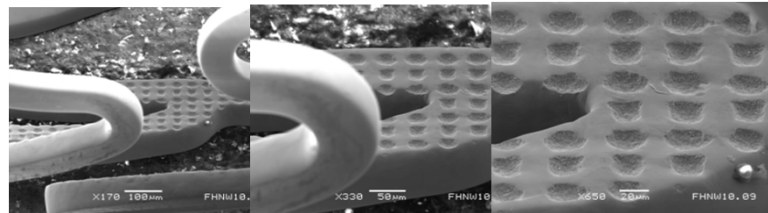
3 Axis 2 ½ D Ablation System:  
 X Linear direct drive; 300mm; Resolution 250nm; Repeatability <math>\lt; \pm 1\mu\text{m}</math>  
 X Linear direct drive; 200mm; Resolution 250nm; Repeatability <math>\lt; \pm 1\mu\text{m}</math>  
 Z Linear spindle drive; 300mm; Resolution 2.5μm; Repeatability <math>\lt; \pm 5\mu\text{m}</math>  
 Operation system Windows 7.  
 Beam expander variable, motorized, 1 – 4x



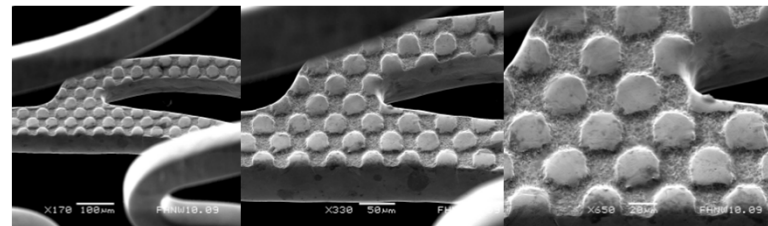
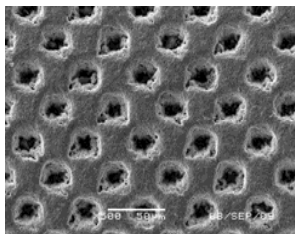
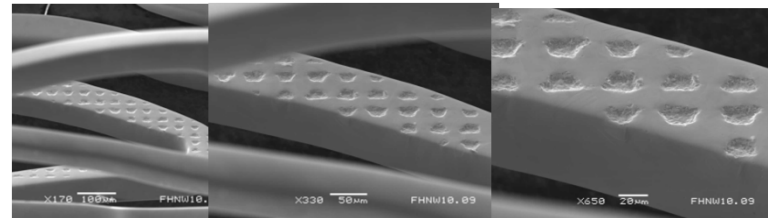
Approach 3: Replication



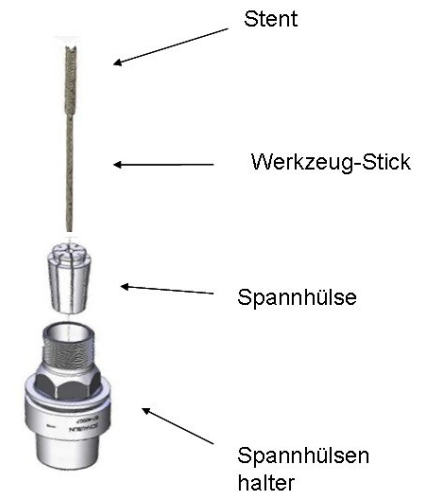
negative structure on embossing tool



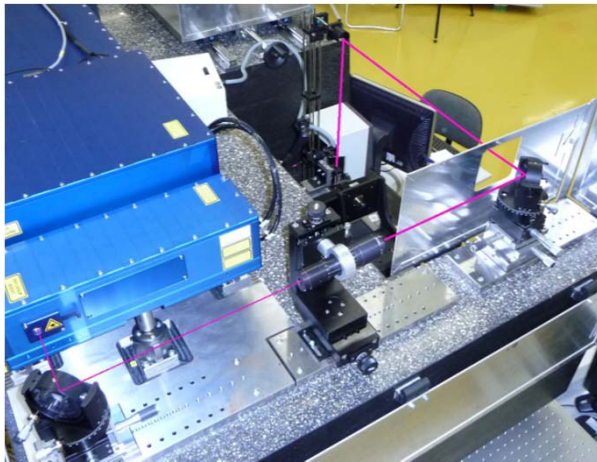
structure on rod with OD of 1.57  $\mu\text{m}$



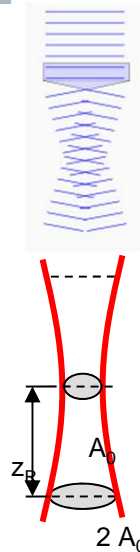
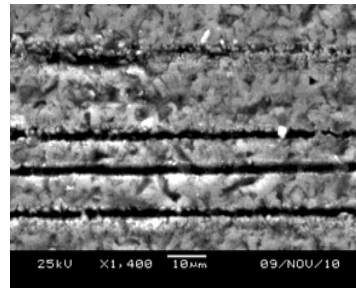
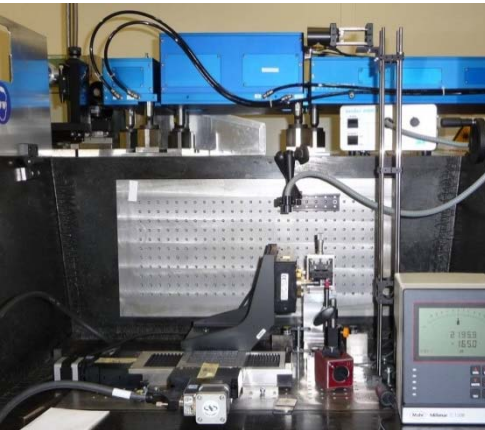
blind holes manufactured by embossing process



embossing tool



JDSU TBWP ps laser (355 nm)



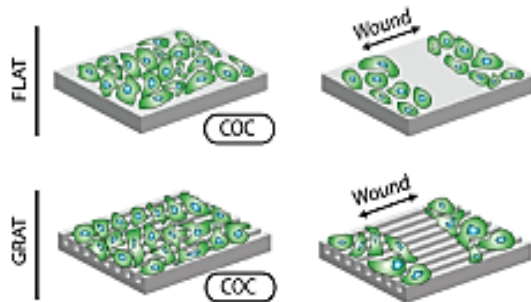
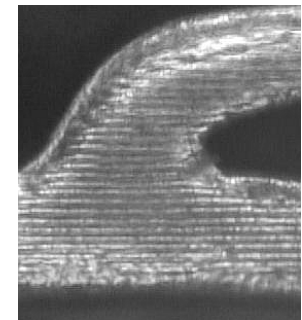
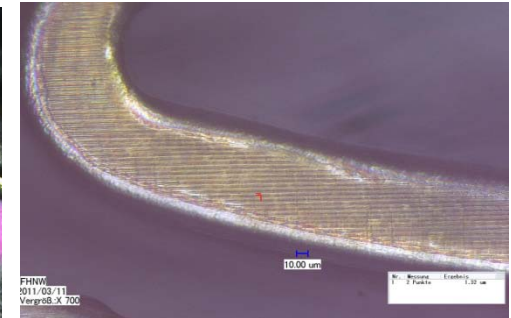
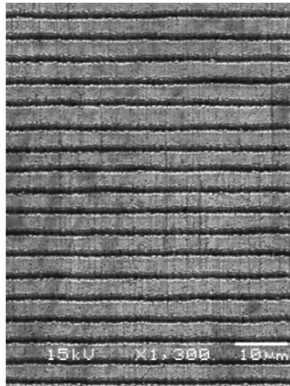
$$w_F = M^2 \times \frac{\lambda \times f'}{\pi \times w_0}$$

- Main problem: required 1 µm spot diameter

- ⇒ focal length 10 mm
- ⇒ wave length 355 nm
- ⇒ beam quality ~1.1
- ⇒ 2 x beam expansion

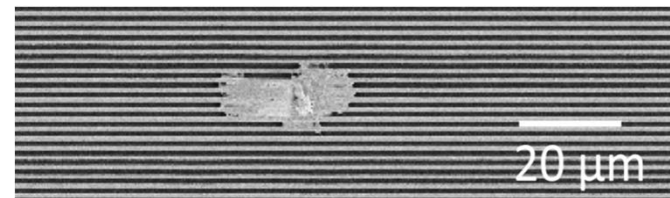
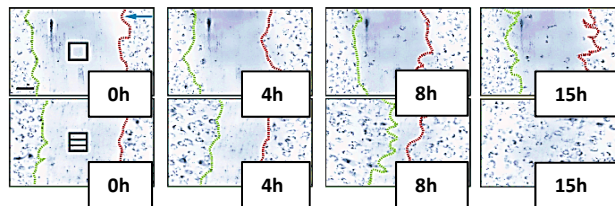
- no Galvanometer with 1 mm focal length
- 4 µm Rayleigh-Länge
- high accuracy axis required

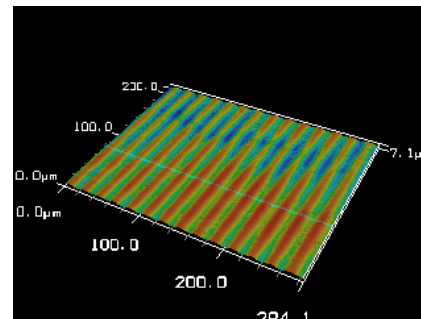
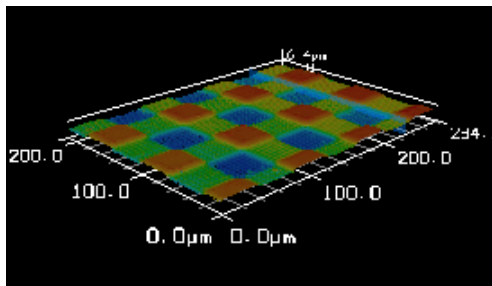
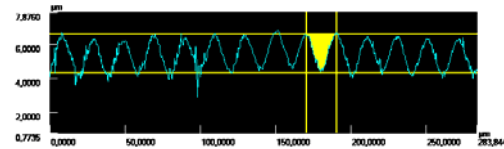
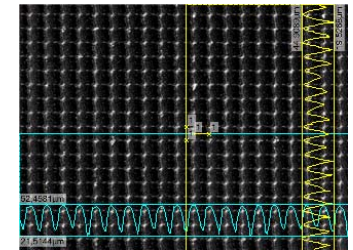
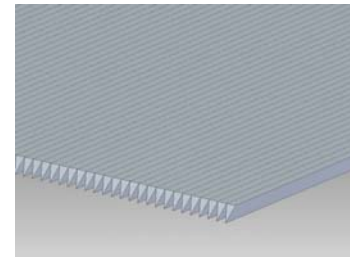
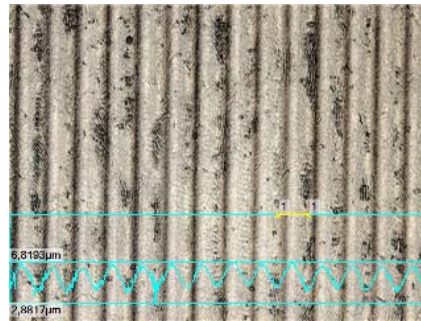
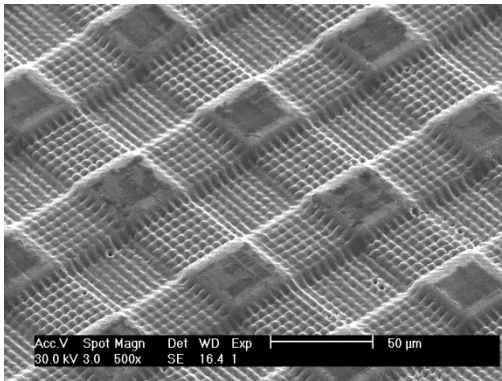
line width	1µm
tool diameter	1.57mm
step angle 4. A	0.073°
Number of lines	4'932
line length	20mm
total length	ca. 100mm



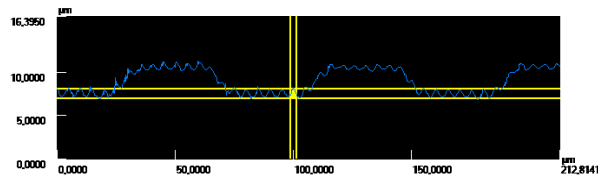
Interaktion of HUVEC cells (Human Umbilical Vein Endothelial Cells) with structured surface

plane structure

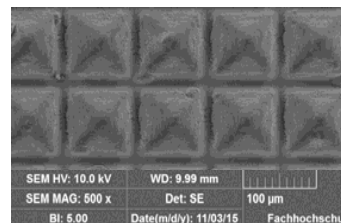




Profil1	Horiz Abst	Vert. Inters	Durchs. Hoh	Winkel	Quers. La	Quers. Fl.	R	Anmerk.
Alle	283,84 μm	0,337 μm	5,4007 μm	0,0680°	330,4082 μm	1314,6863 μm		
Seq.1	20,27 μm	2,2929 μm	5,5294 μm	6,4524°	22,3824 μm	25,4199 μm		
Seq.2								

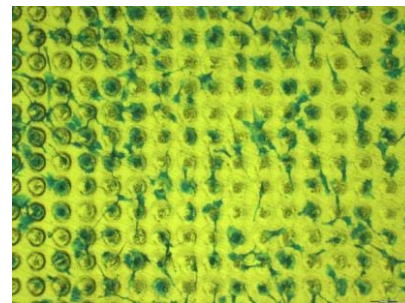
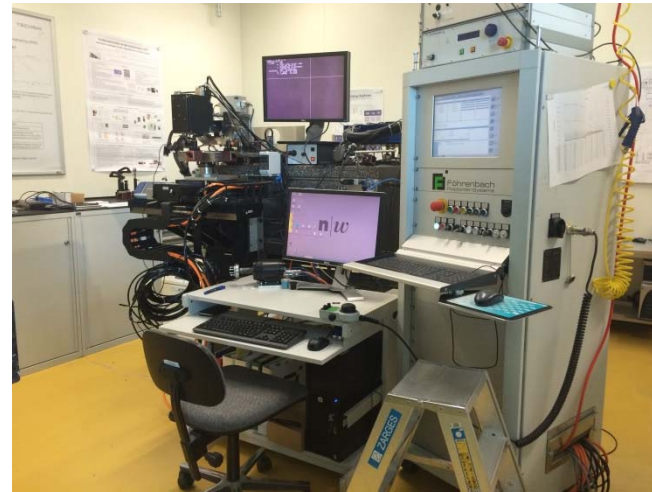
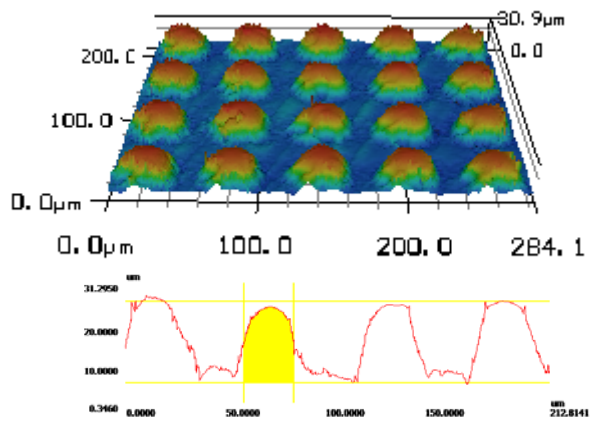
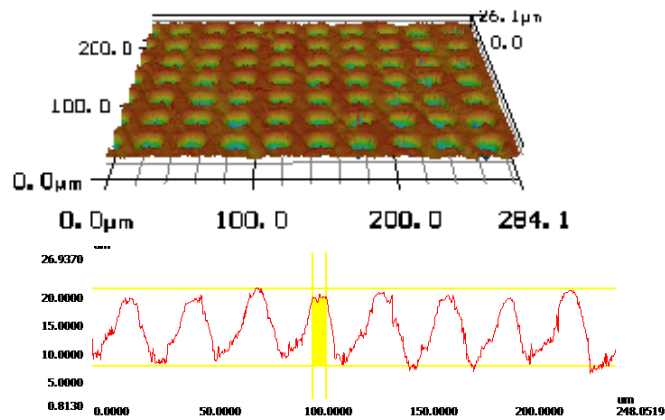


Structure width:  $\approx 2.5 \mu\text{m}$   
 Structure height:  $\approx 1 \mu\text{m}$

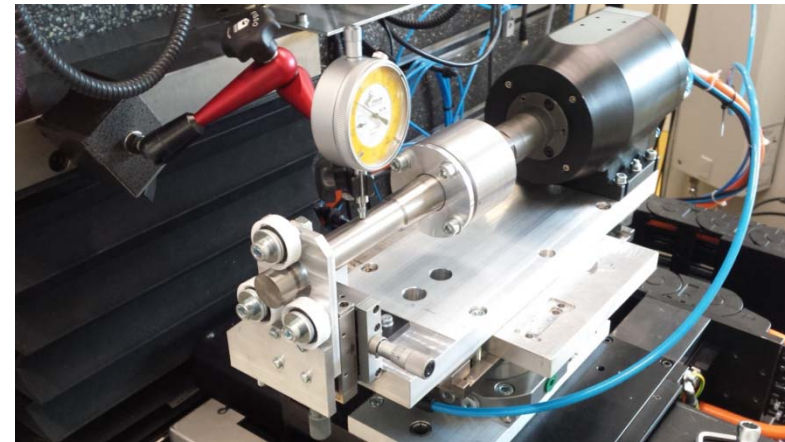
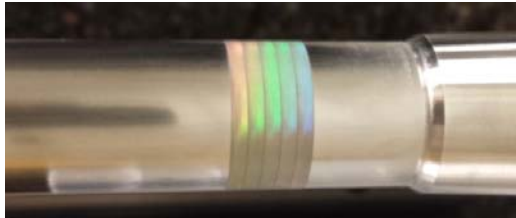


Duplication by injection molding



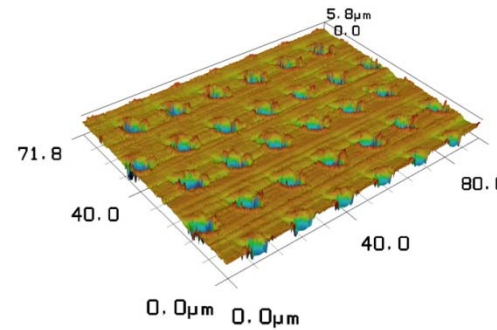


Cell response (here for MC3T3 osteoblasts) to round pillars with diameters of 10 μm

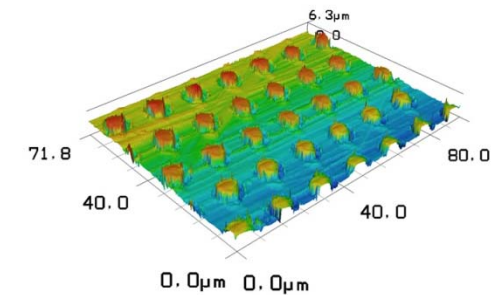


Objective: friction reduction with proven sealing

Scale	Model	Factors	Friction Pattern
$10^{-3}$ m Macro	Contact Mechanics	Mechanical Properties Topography Surface Forces Heat	Deformation
$10^{-6}$ m Micro	Mechanics of Discrete Contact		Adhesion
$10^{-9}$ m Nano	Nano-mechanics		



Structure 1 (negative)



Structure 1 (positive)

- Approach 1:
  - market development needs time, depends on upcoming technology
  - handling of market fluctuation challenging
  - strong competition between manufacturers
- Approach 2:
  - direct competition under strong cost pressure
  - waiting for fast beam delivery in combination with low cost beam sources
- Approach 3:
  - most promising, due to low cost pressure
  - closing gap between lithography and mechanical machining

Thank you for your kind attention!

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- Review of some years of process development with ultra-fast lasers
- Market penetration still low comparing to conventional laser equipment
- High volume key markets: medical applications, consumer products
- Many highly customized specific applications
- Reasons: costs, beam delivery, performance