

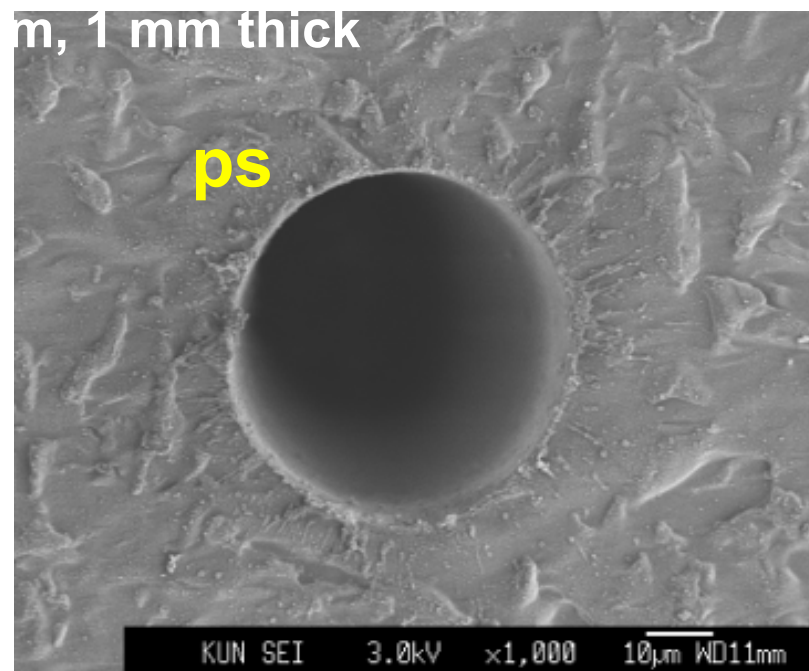
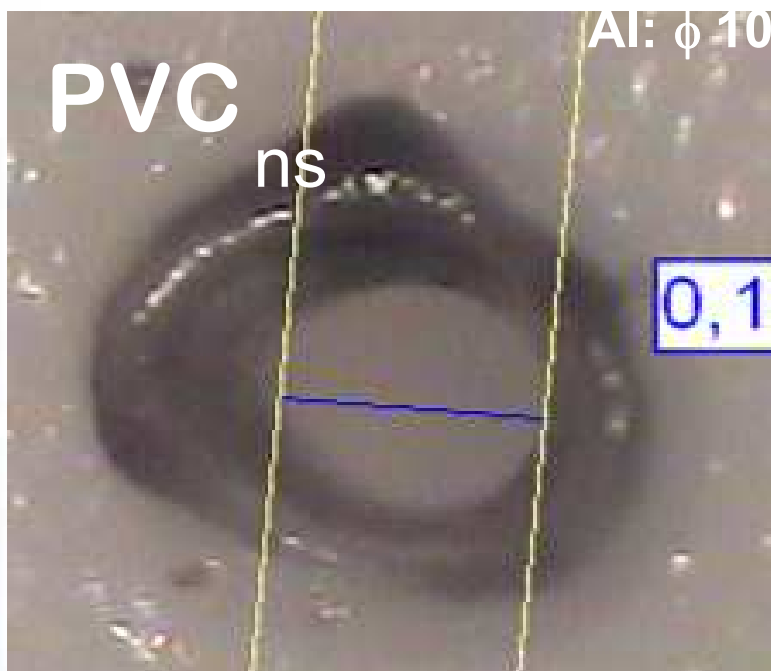
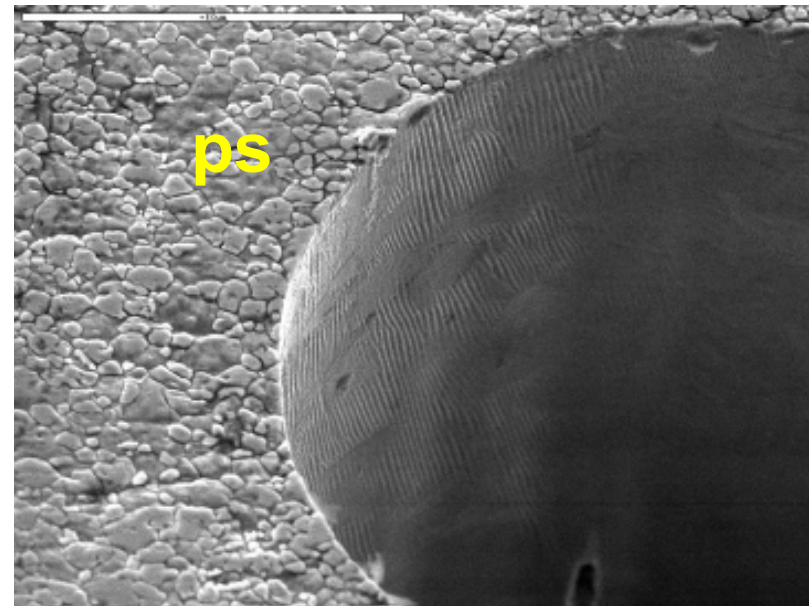
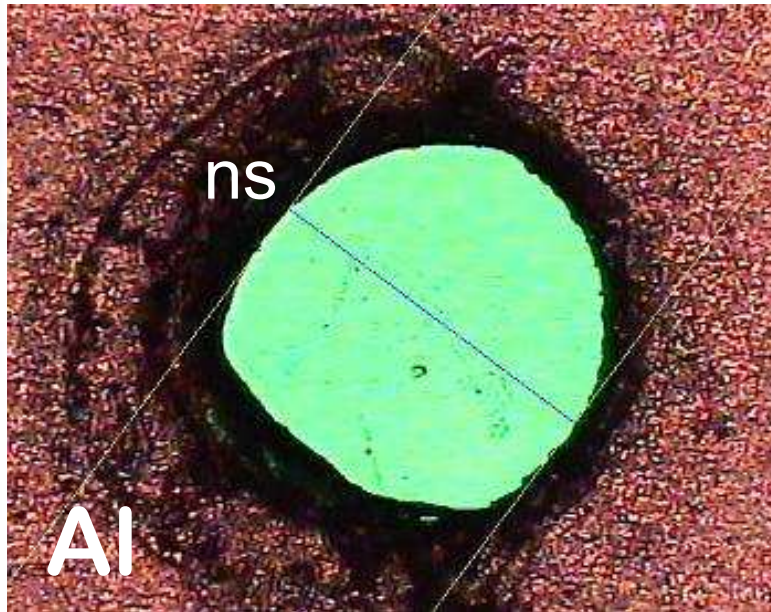
Picosecond Laser for Micromachining: Quality, Speed, Cost

*Bernhard Klimt,
Hatim Haloui, Dirk Müller*

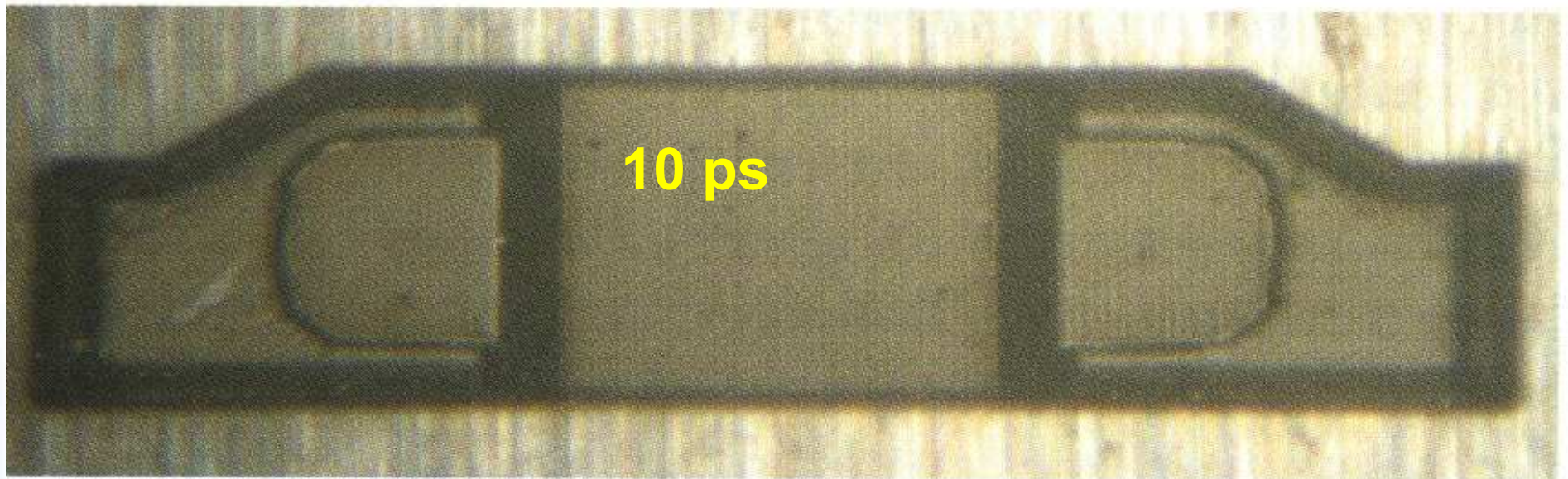
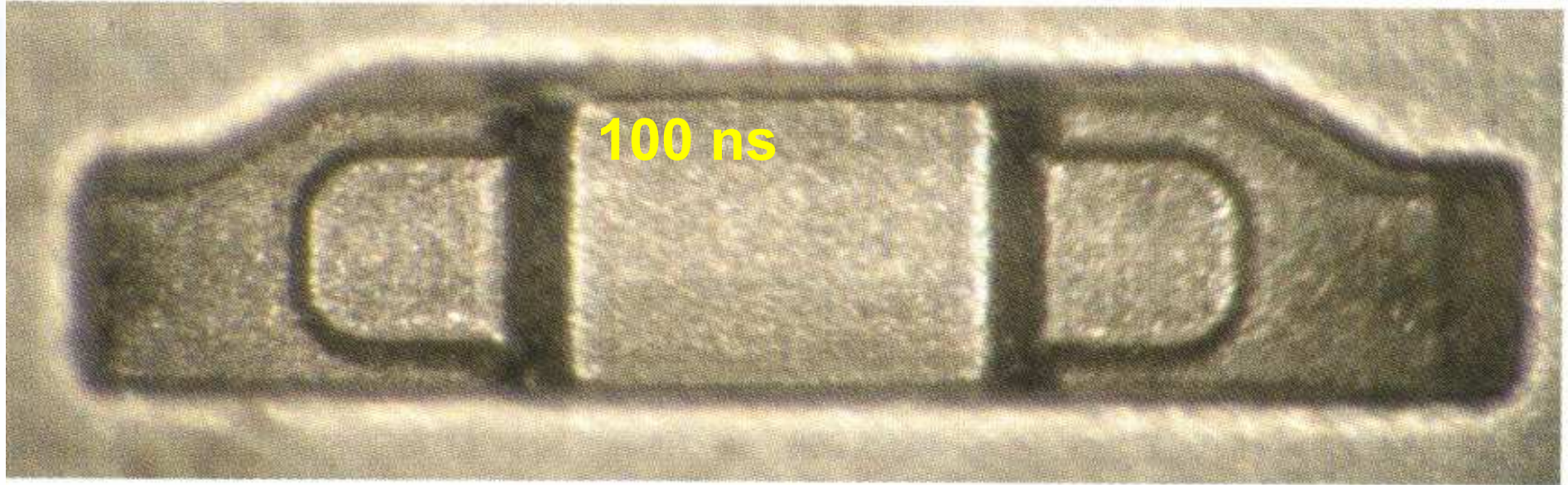
[www. LUMERA-LASER .com](http://www.LUMERA-LASER.com)



machining with ns vs ps-laser

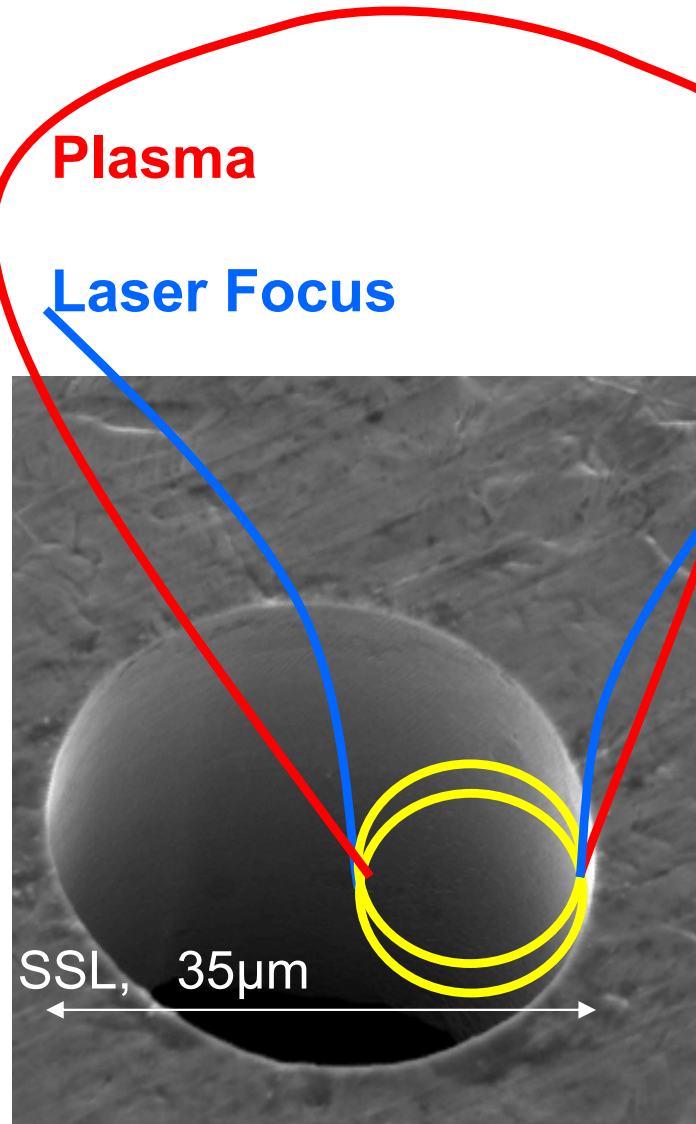


Micro mold in SST, ns vs ps laser



Executive summary

**industrial
picosecond laser
RAPID series**



**removed
material:
20-100nm thick/
pulse;
typ. dia 1-50µm**

**no thermal
damage, high
quality**

**any material!
up to 2mio p/s**

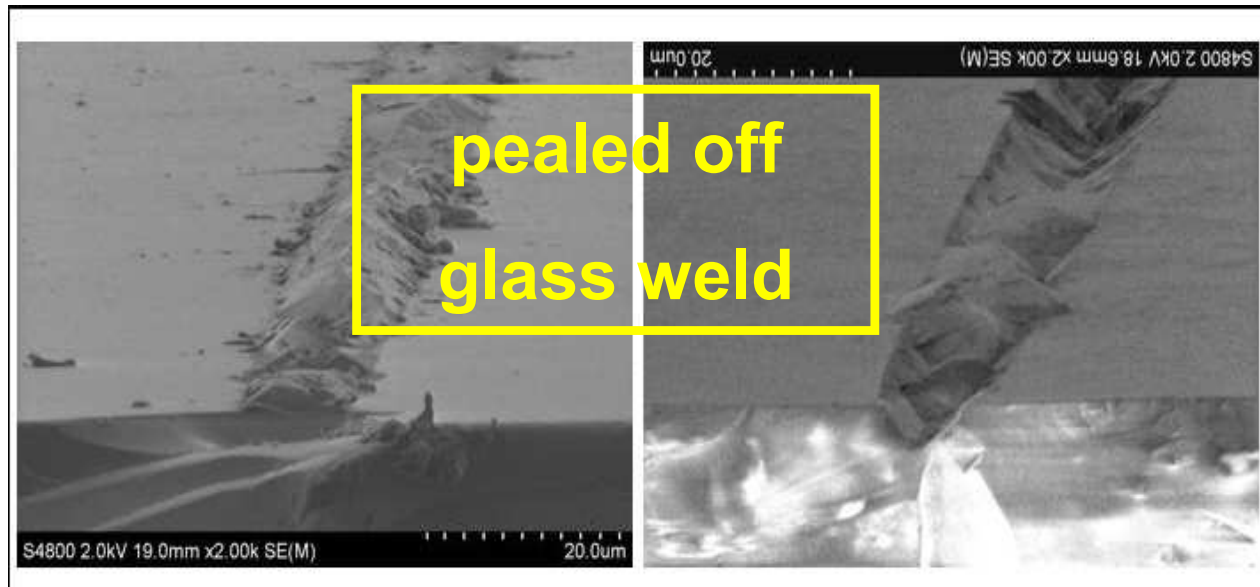
**6-60mm³/min
(50W)**

TCO: ~0.2€ /min

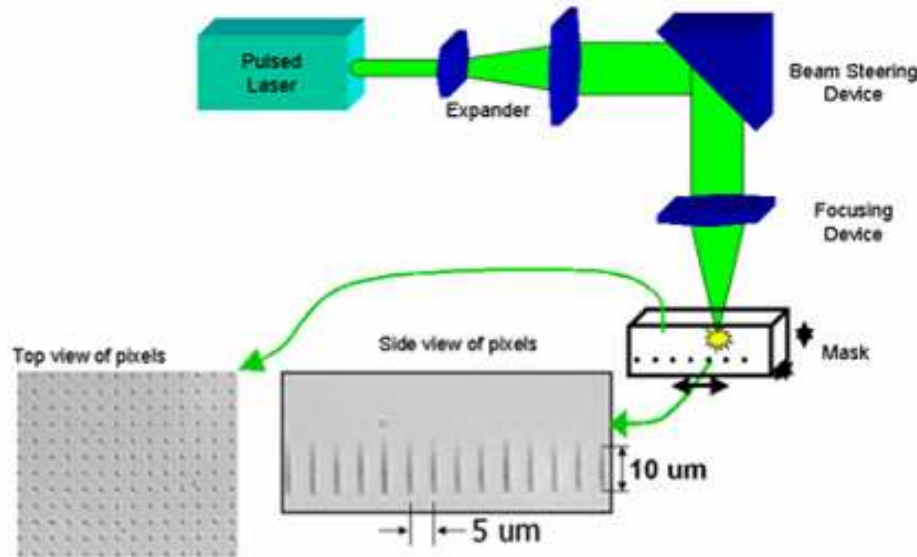
- High quality, micro technology:
micromaching + others
 1. **“cold” ablation** (stoichiometric plasma; generate nano-particles; create coatings; remove mass; **create micro-structure**)
 2. glass welding (thermal)
 3. change refractive index in glass voxels
 4. internal color change, marking
 5. internal scribing/perforation (for separation)

2. Glass welding

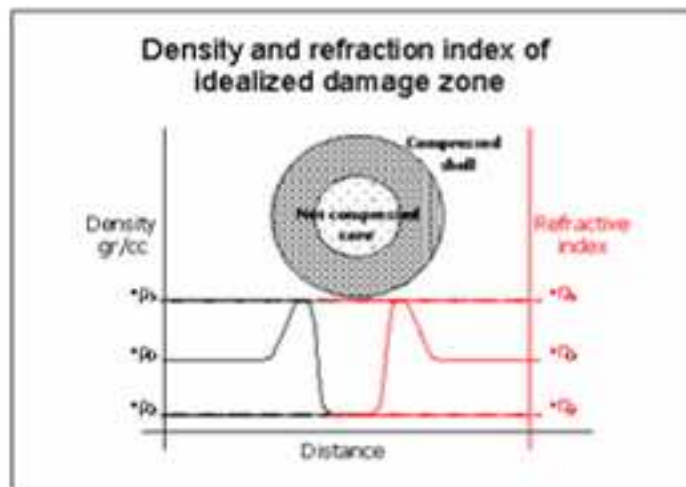
- 10ps, PRF 500kHz ; $\sim 3\mu\text{m}$ focus, $\sim 1.4\mu\text{J}$, 1064nm
- Fusion welding of different glass plates (fused silica, display glass / Schott D263) without cracks and thermal distortion:
joining, sealing displays?
- $v > 100\text{mm/s}$; high joining efficiency
- *Characteristics of internal melting of glass for fusion.. Miyamoto, Herrmann; LMP 2007*



3. Change of refractive index



Side view of a Shade-In Element™



Change of refractive index

- **PIXER:**
in voxels of mask material (glass) to **correct CD of lithographic masks: yield increase!**

- **wave guide writing**

4. *Internal color change*

..in transparent materials

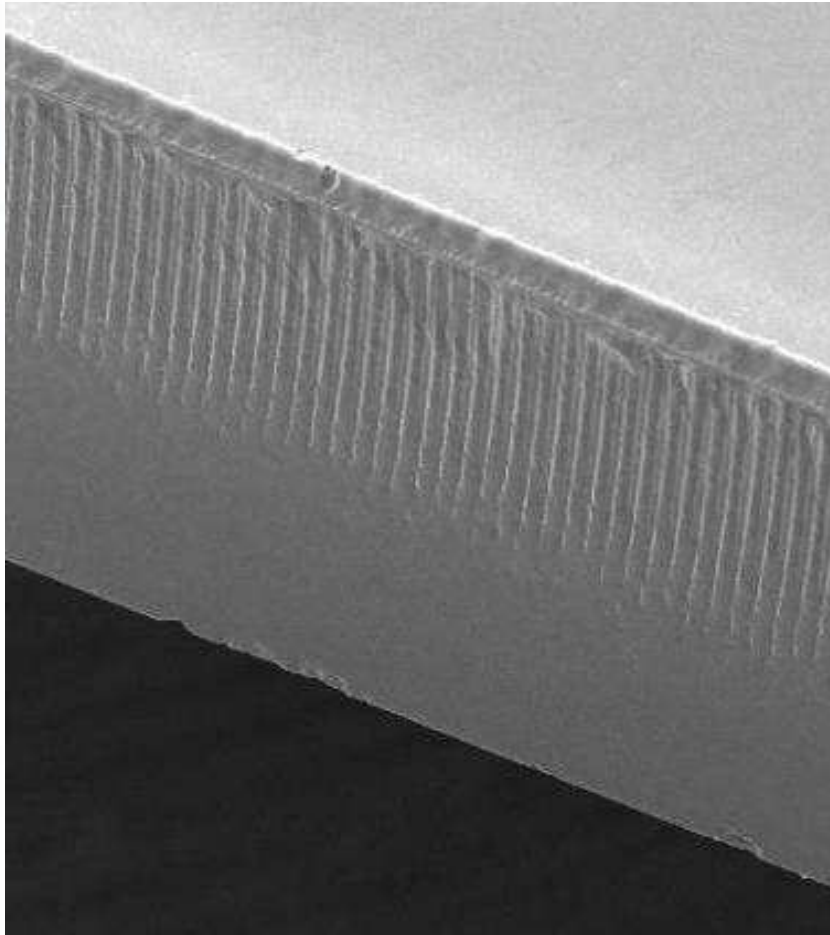
- marking:

internal product identification (glasses,
medical devices..)

copy protection



5. Internal scribing

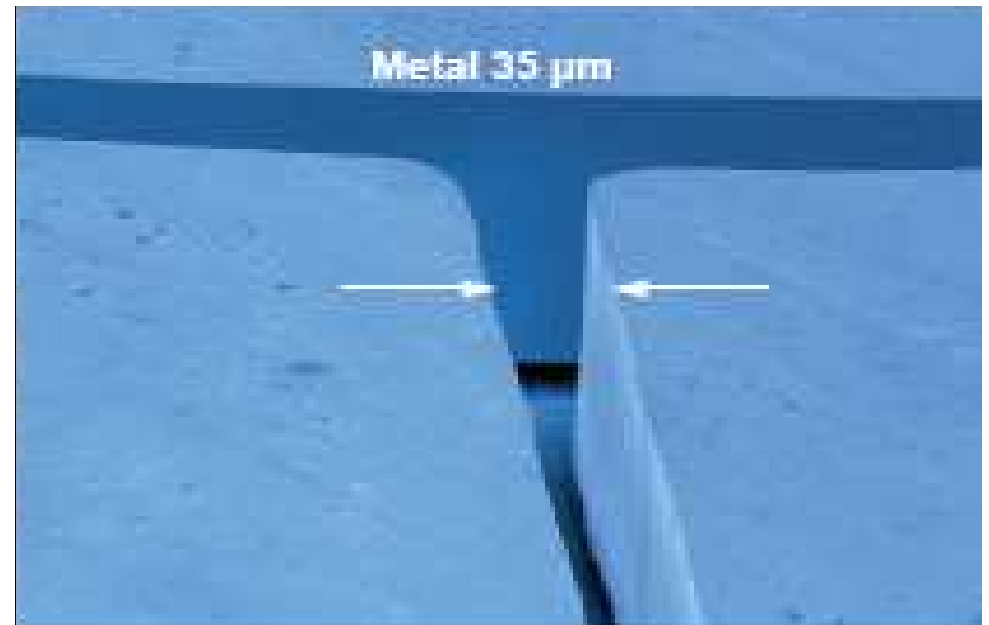


- ..in transparent materials:**
- separation of glass up to 1mm thickness,**
- up to 1m/s ! , CAD-curved**
- no debris, no electrically charged particles on surface**
- patented process with fast auto-focus**

1. Ablation

..of any material with the same laser!

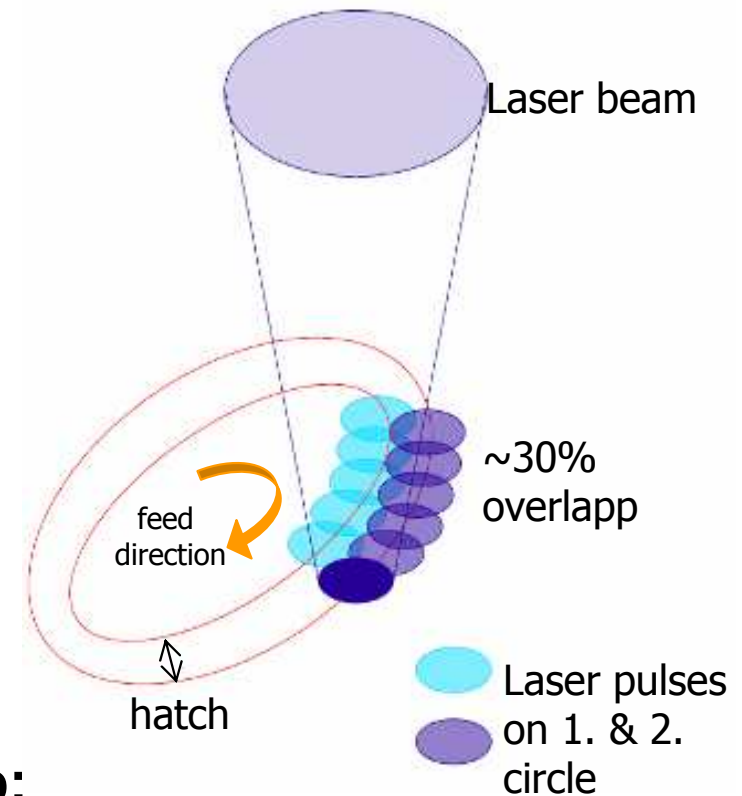
- generation of stoichiometric plasma for analytics, spectroscopy etc.
- nano-particles, generate coating
- tune mass by micro-ablation (μm^3 , ~femtoliter, ~picogram)
- **micro-structuring with high resolution and high quality**



1. **Mechanical: $>50\mu\text{m}$...; CAM**
2. **Ultra sound: $>50\mu\text{m}$, selected materials**
3. **EDM: conductors only , $>50\mu\text{m}$**
4. **Chemical / Lithography: high resolution, high through put for large batches; high cost, long lead time, waste disposal**
5. **Lasers (cw-ns): no wear and tear, no touch, no force, no contamination, CAM, lots of 1, all software controlled; but thermal side effects $>10\mu\text{m}$, micro cracks, recast, burr**
6. **ps-lasers: hardly any thermal side effects; quality improved by more than 1 order of magnitude!
~20-100nm thin slice in focus area removed by 1 pulse
universal tool for all materials
Especially useful for 50-1 μm and tough materials!**

Application parameters

- Ablation **threshold** 0.2 – 2J/cm²
- Micromachining **dimension**,
focus ~dia 10µm:
- **pulse energy** E ~1µJ
System losses; SHG, THG?
Larger spots? **bursts** : ...50µJ
- **Through put**: high **PRF up to 2MHz**
Ablation rate with HYPER RAPID
50W:...~60mm³/min, ...~10⁹ µm³/s:
Process speed: e.g. trench with
20mm³/min: ~33µm wide, ~1µm deep:
up to 10m/s
- **Result**:
in 1 min 600m trench for ~0.2€ TCO!



Micromachining Systems



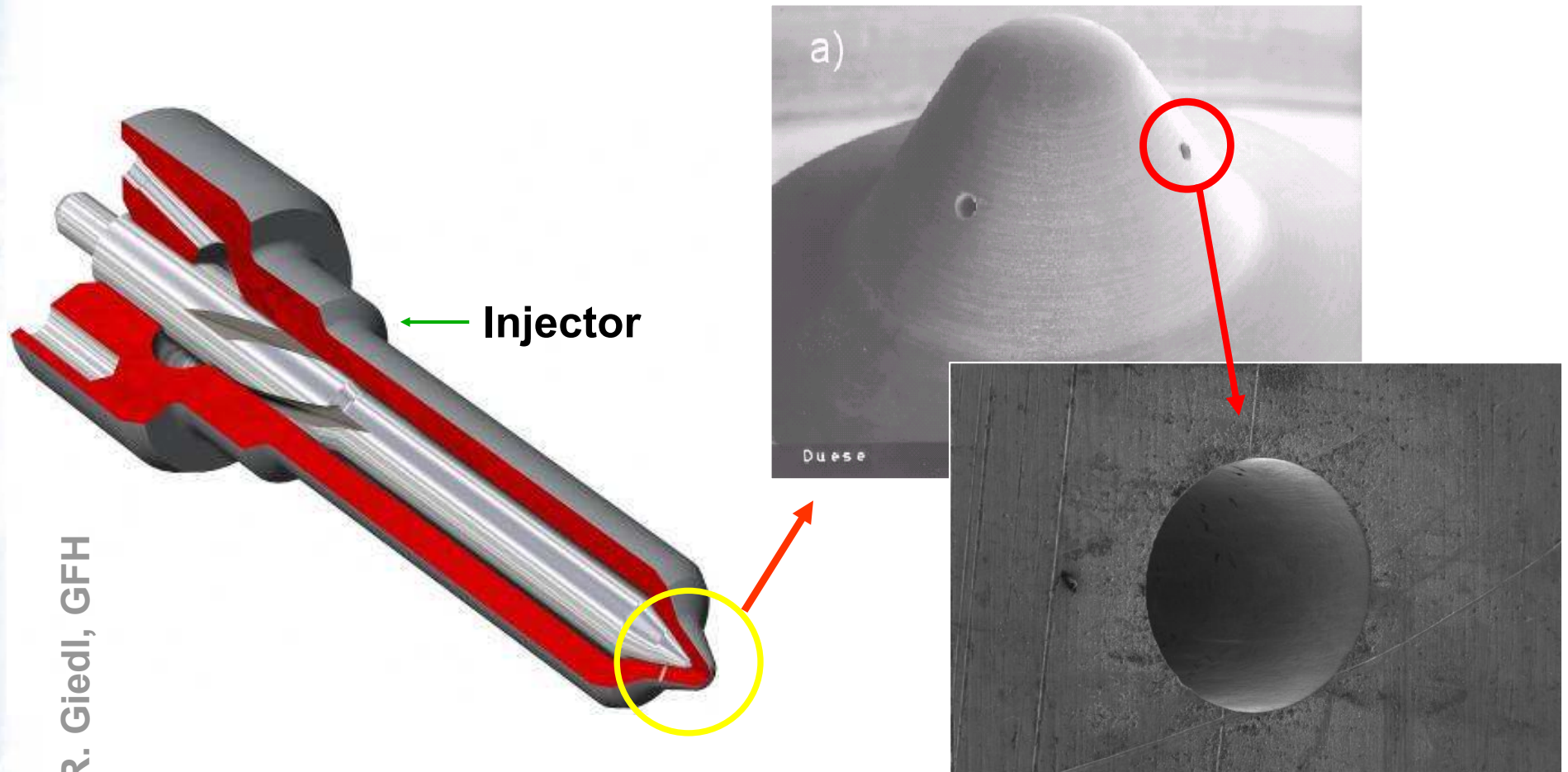
...with picosecond laser



LASERTEC 40 PrecisionTool
www.gildemeister.com

Applications examples
a variety of different materials..

Drilling of injection nozzles



Source: R. Giedl, GFH

Spray holes: $\varnothing \sim 100 \mu\text{m}$, $P > 1000 \text{ bar}$

Nozzel drilling



1mm thick SST

60 / 120 μ m

532nm, 25W

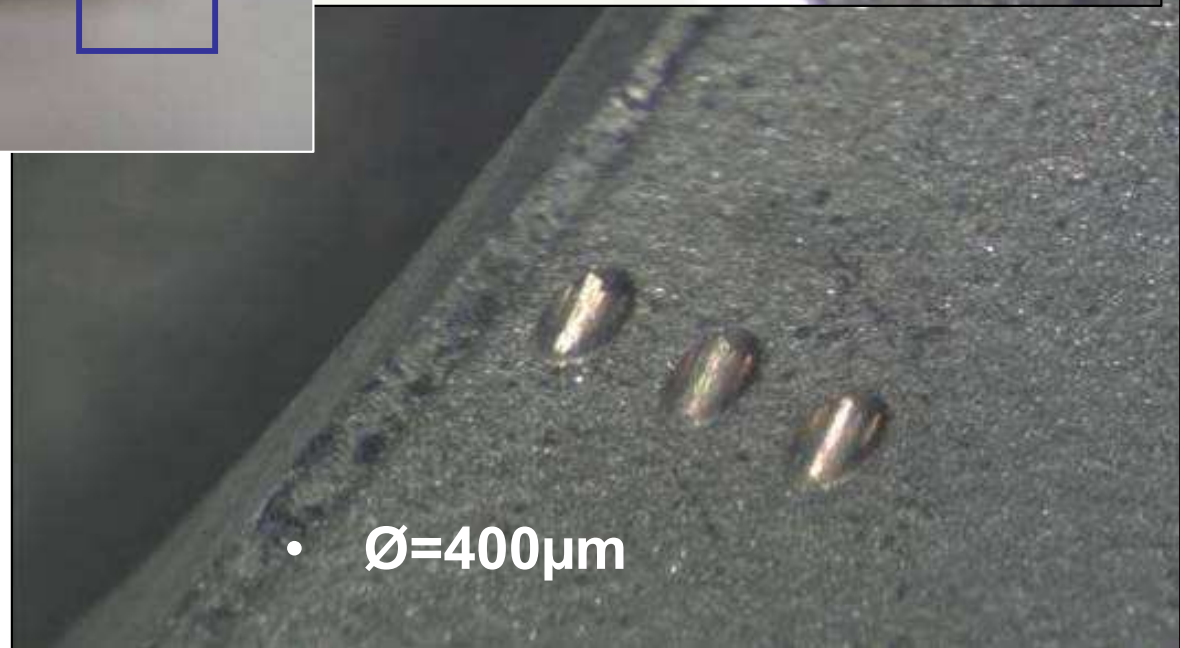
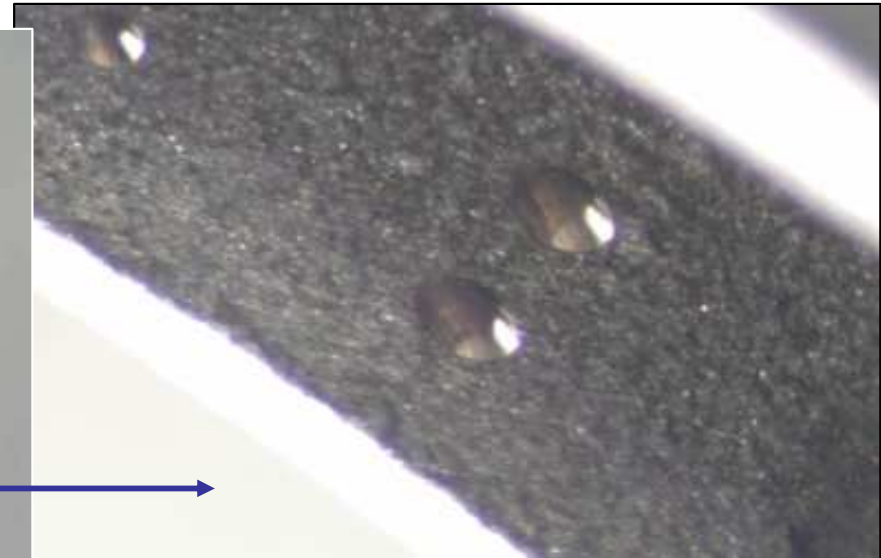
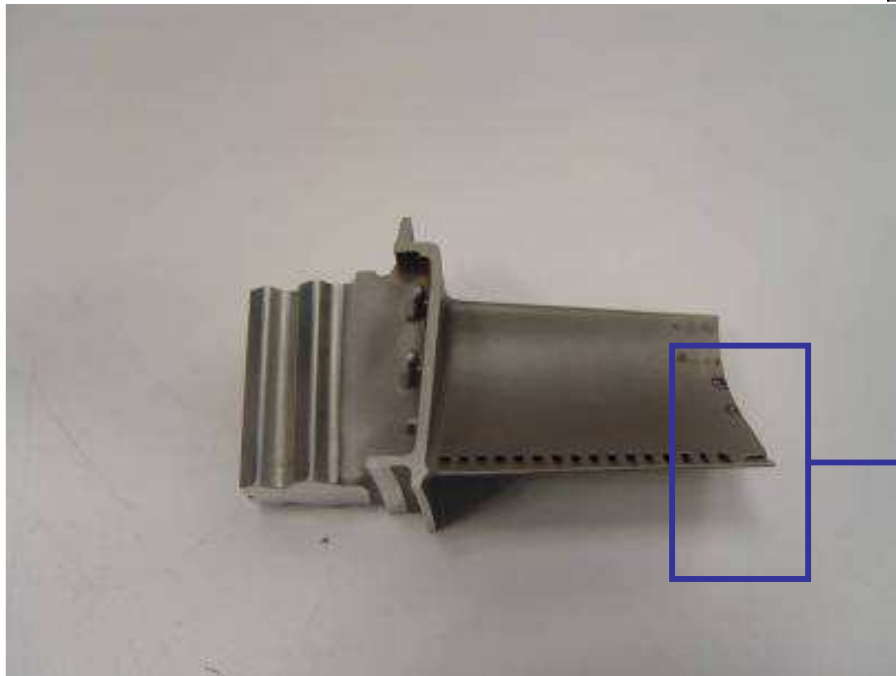
500kHz

Through in 5s

Ready in 15s

Courtesy of ExOne

High aspect ratio holes, tilted

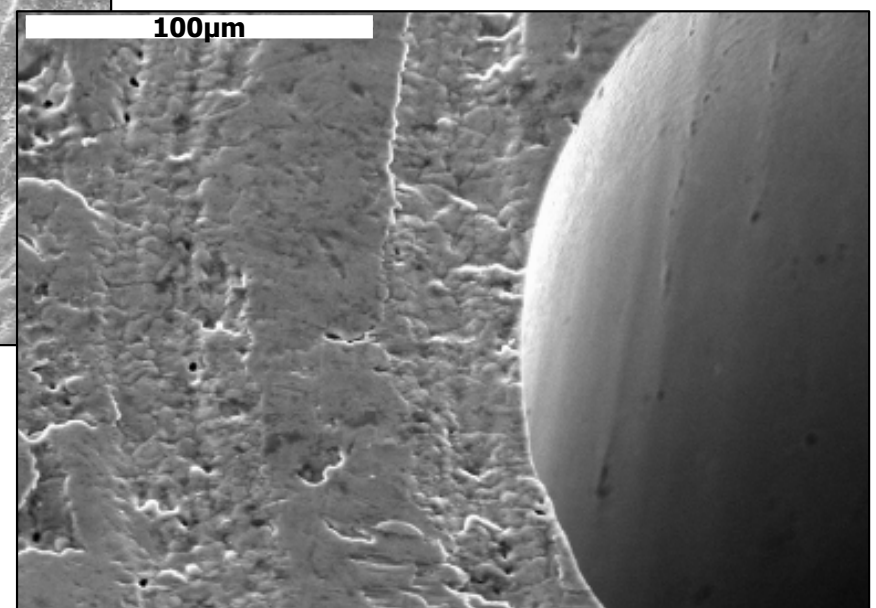
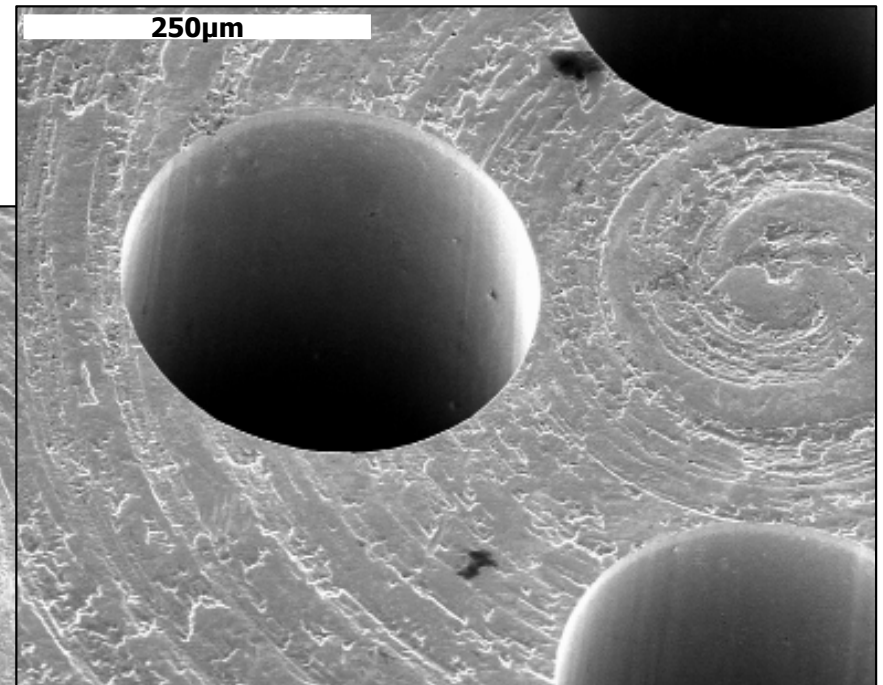
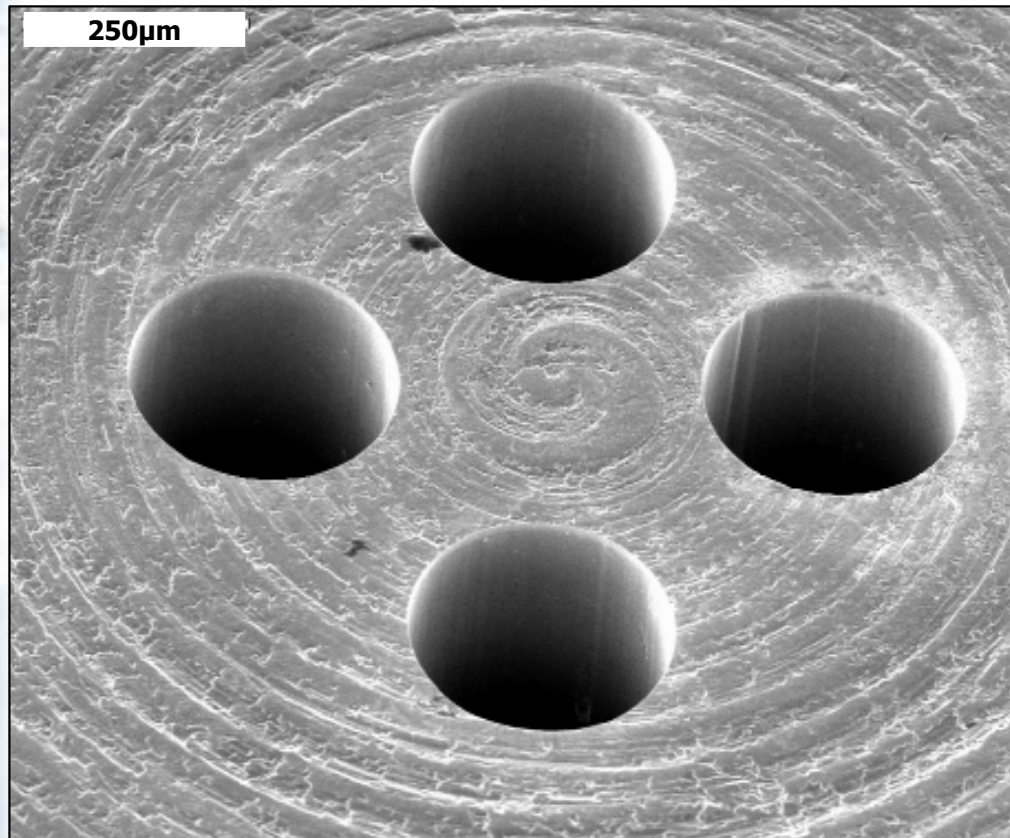


1mm Ni-alloy
400 μm dia
60° tilt

Very good
surface quality

Stainless steel drilling

$\varnothing=250\mu\text{m}$, thickness: $300\mu\text{m}$

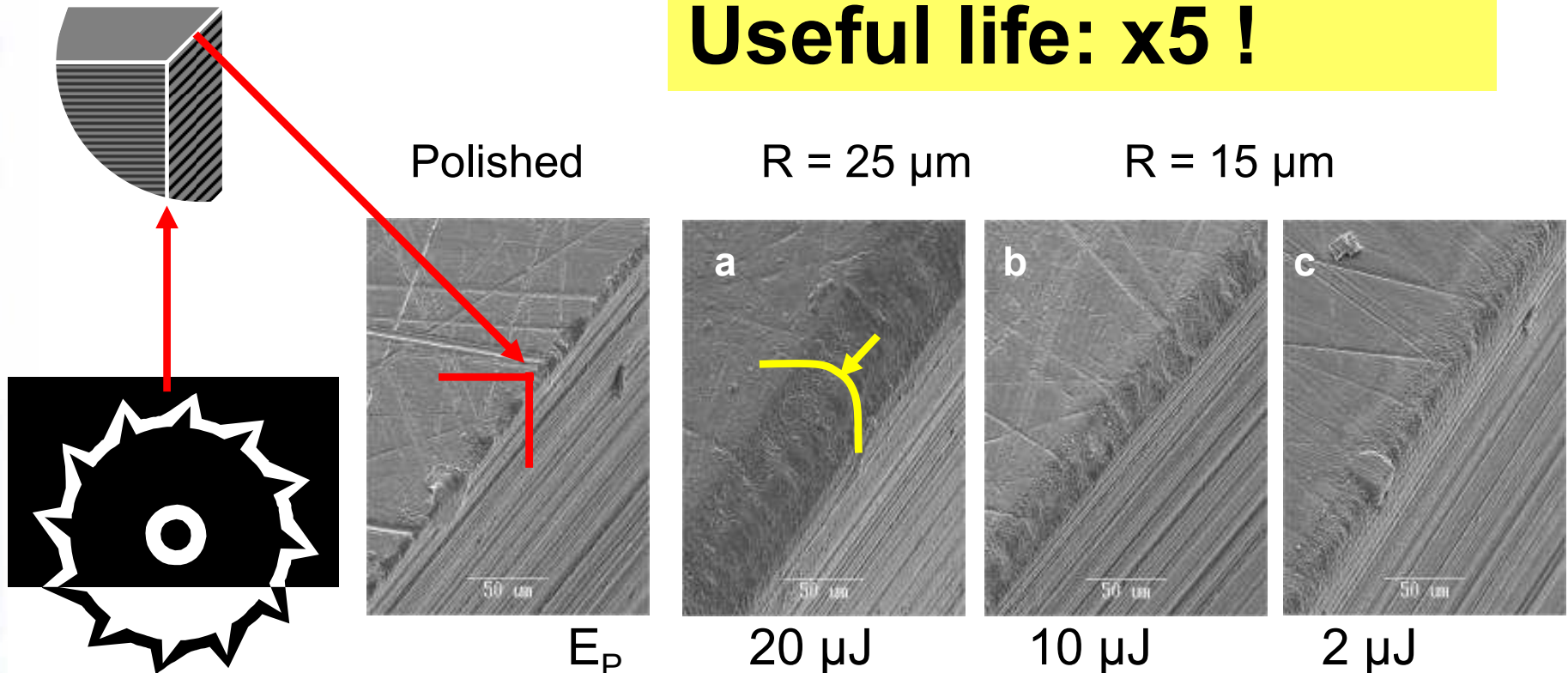


processing time : 5s / hole

Edge rounding on Tools

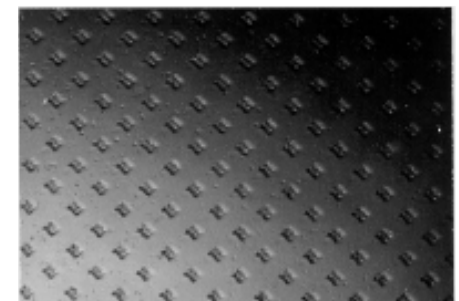
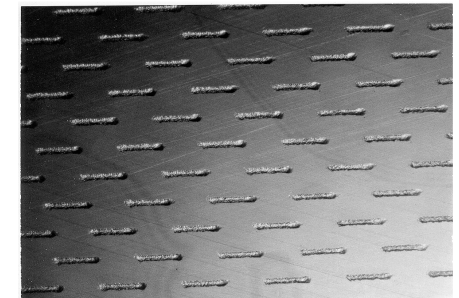
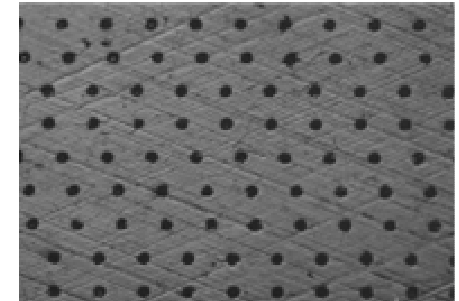
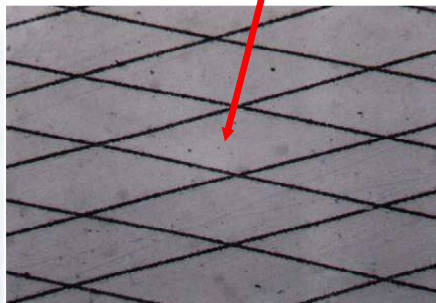
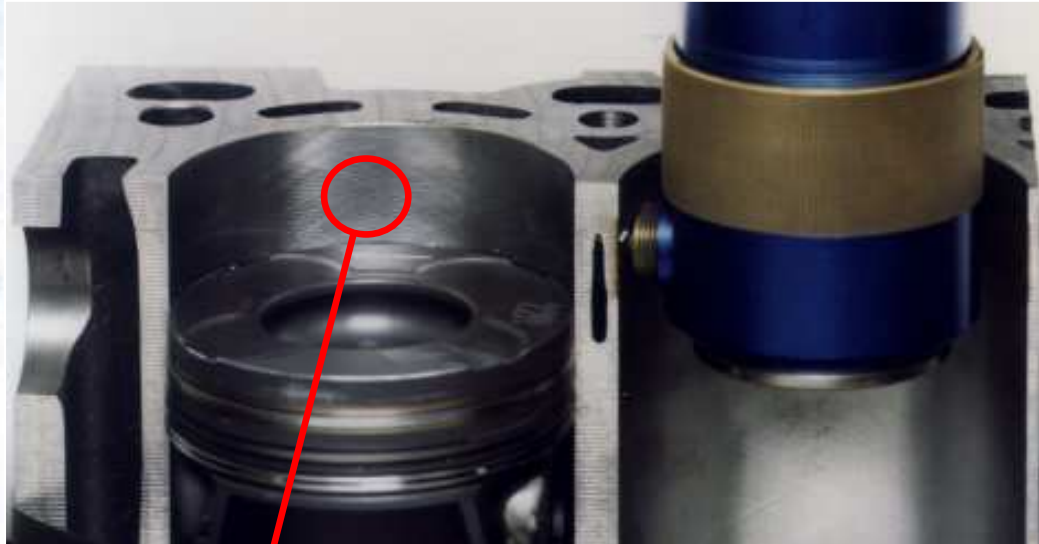
Edge rounding of carbide metals for High-Precision Tools (www.geospan.de)

Useful life: x5 !



532 nm, 30 kHz, 1 mm/s; use 1000 kHz \Rightarrow 30 mm/s

Reduced Friction



**Advantage:
Reduction of oil consumption
(3 to 7 fold)**

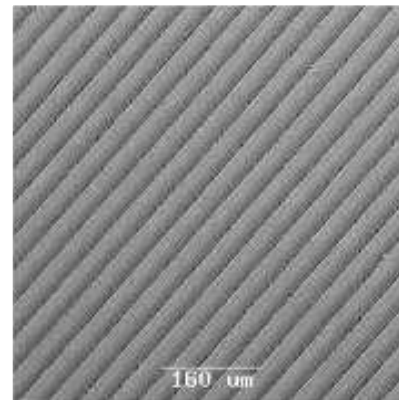
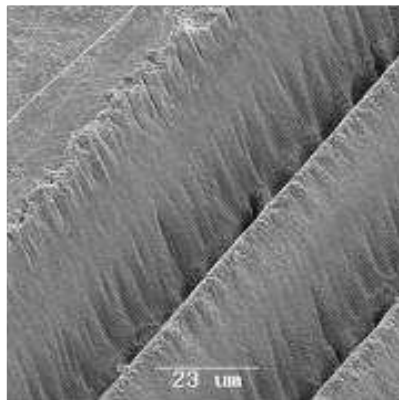
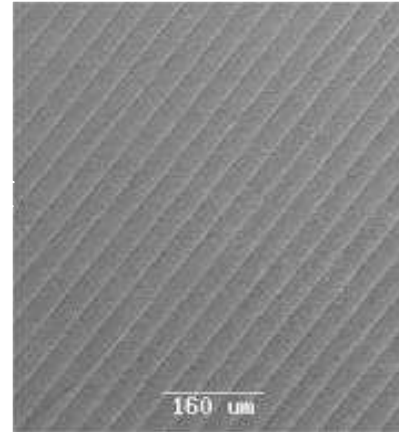
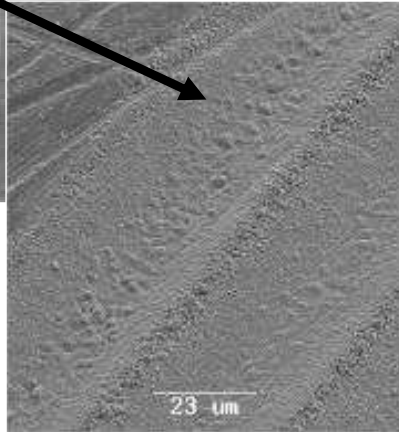
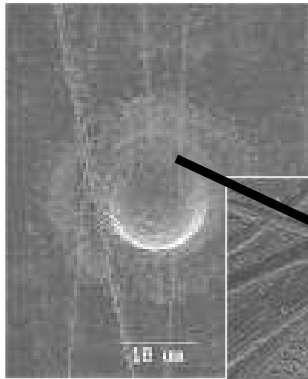
Reduction of particle emission

ps: precise, no post-processing

Source: Gehring

Reduction of Friction

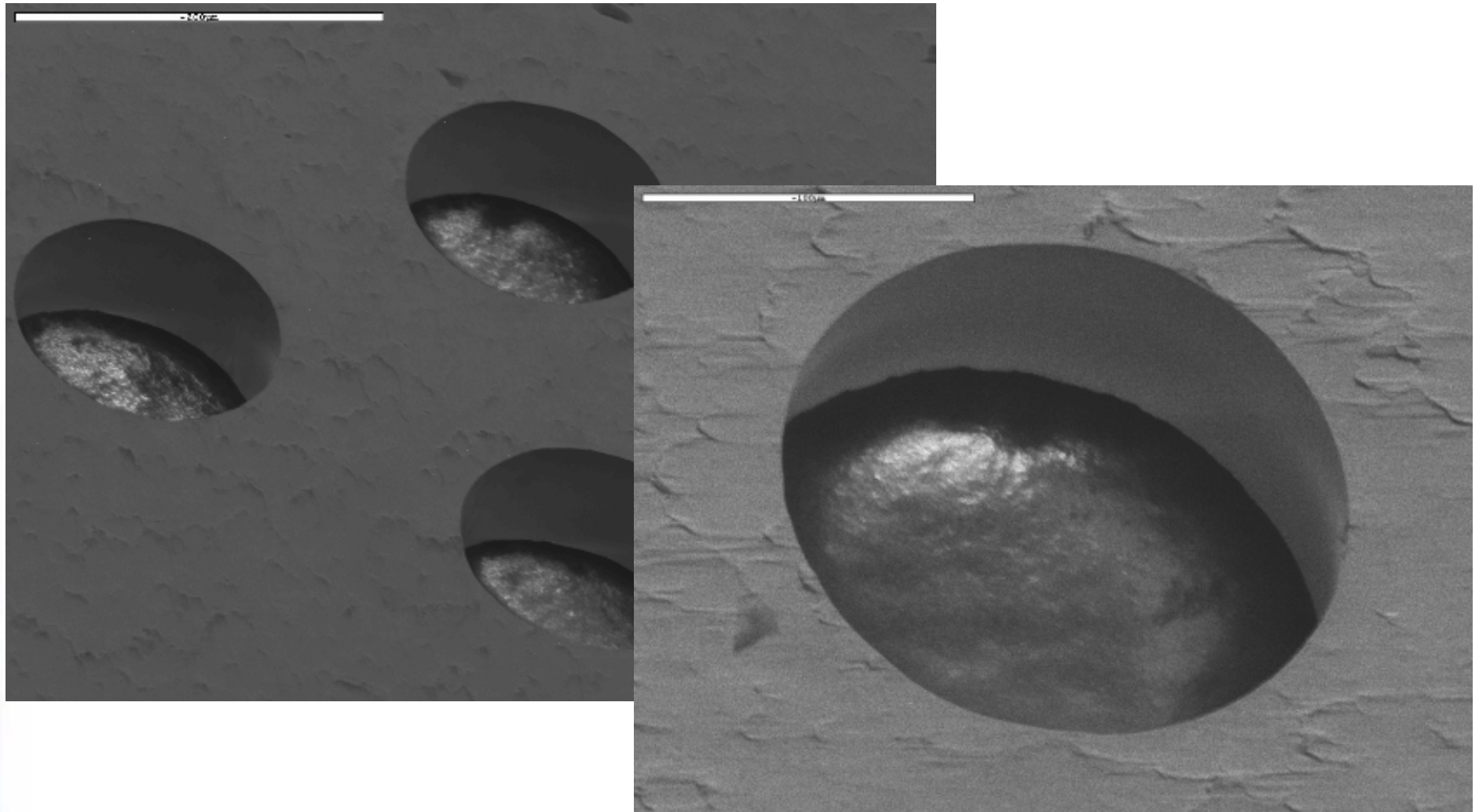
microstructures on metallic surfaces with reduced friction



Courtesy of Frank Siegel, LZH

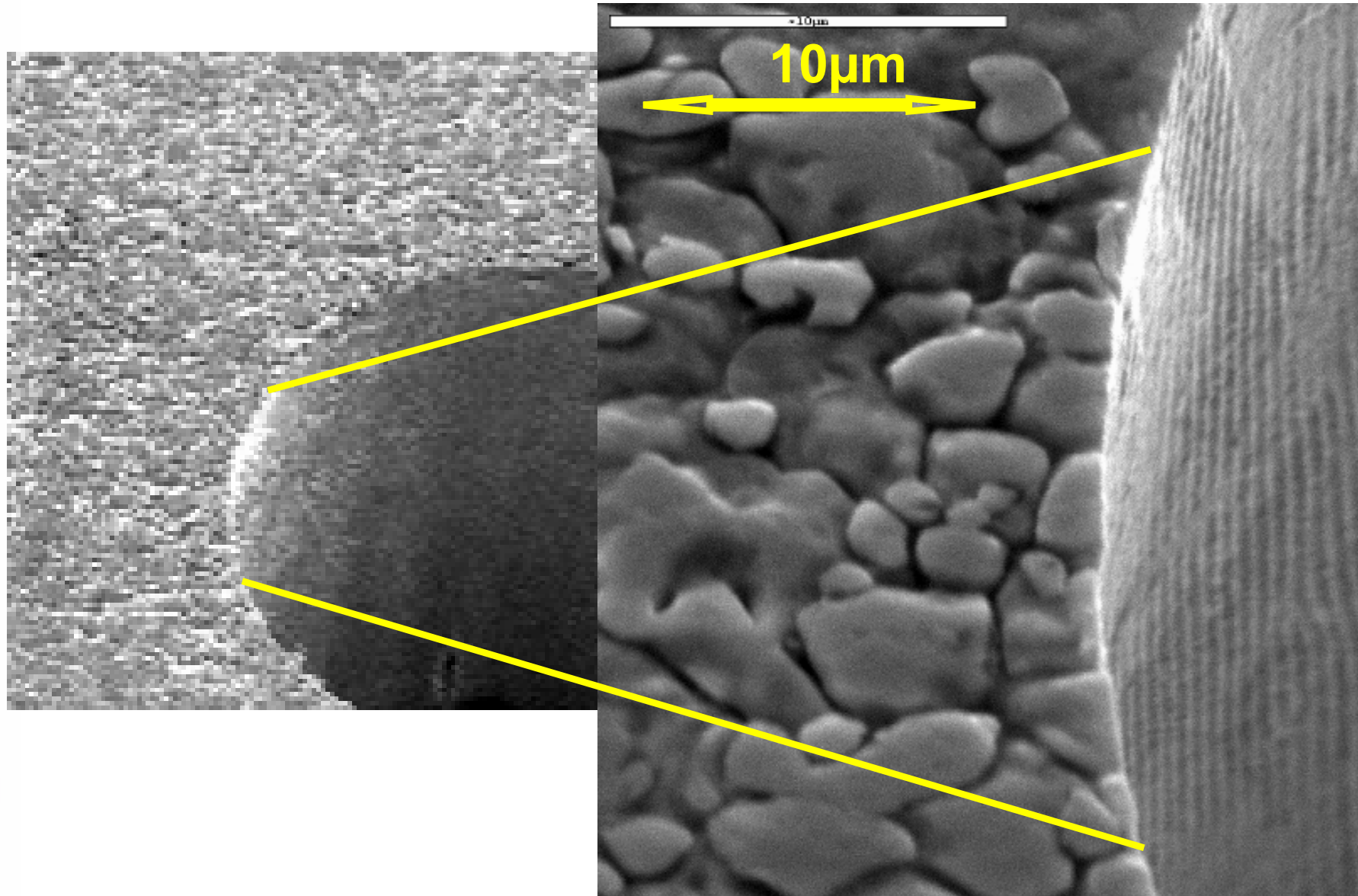
Molybdenum 180 μ m holes

LUMERA LASER APPLICATION LAB:

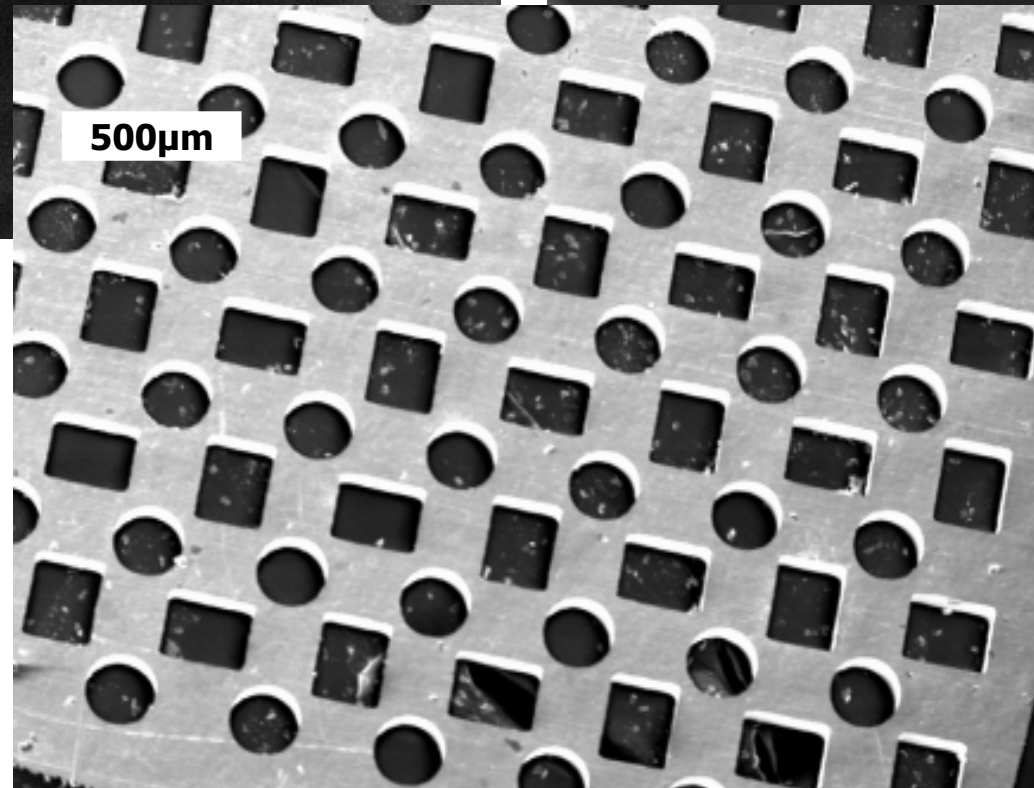
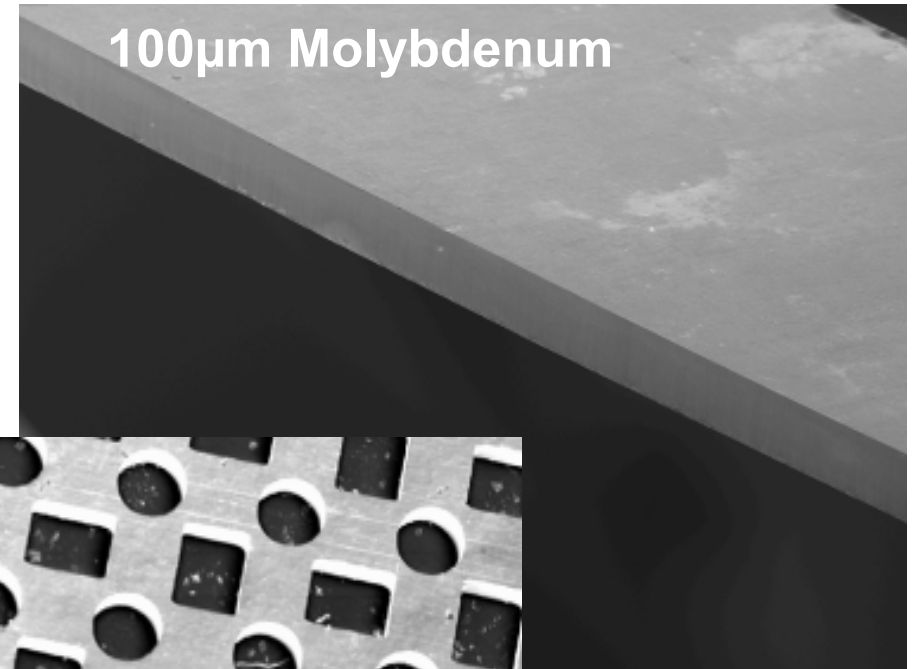
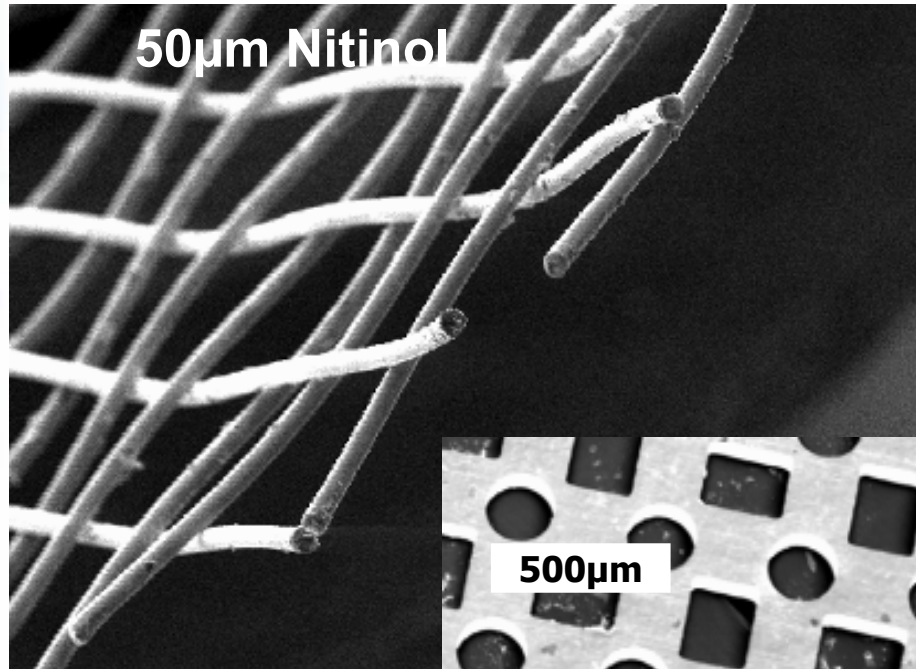


150 μ m hole in 0.5mm Al

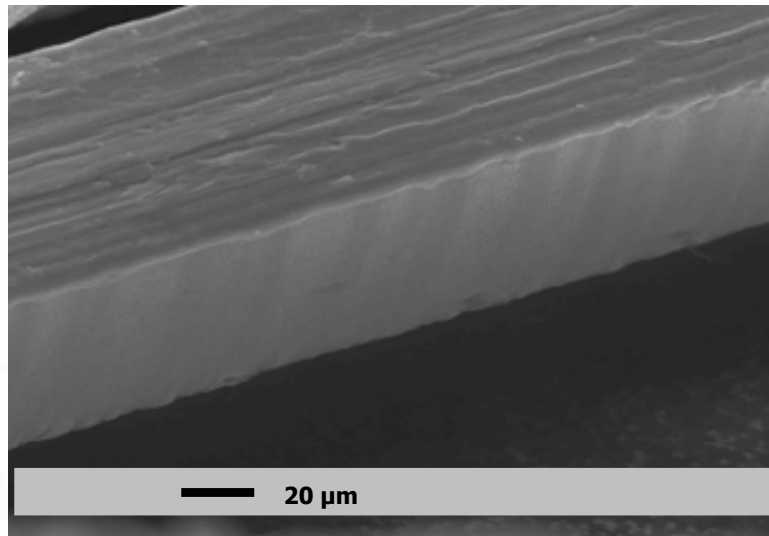
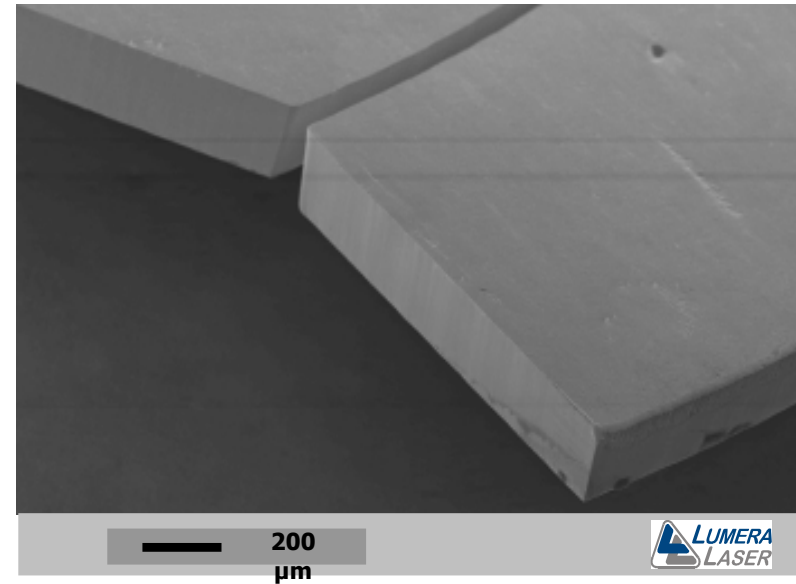
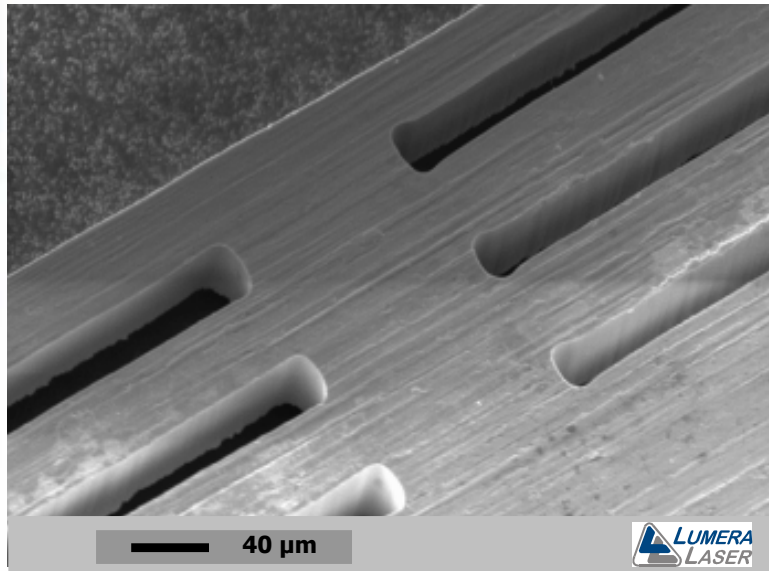
LUMERA LASER APPLICATION LAB:



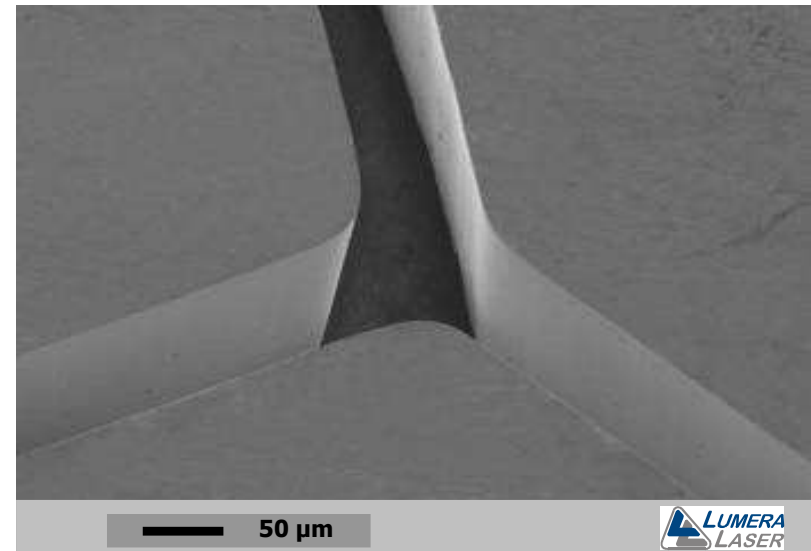
Cutting of metals



Slots in metal foils

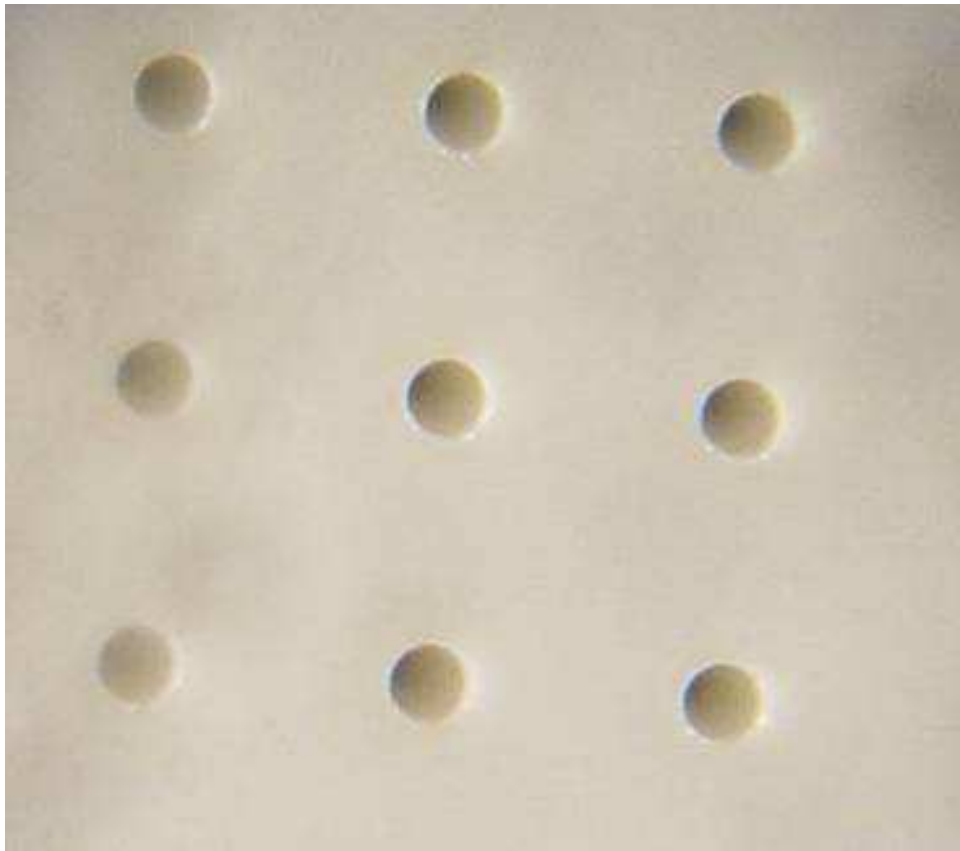


15μm slots in 20μm metal alloy



30μm slots in 100μm tungsten

Holes on ceramic



Diameter : 100 μ m

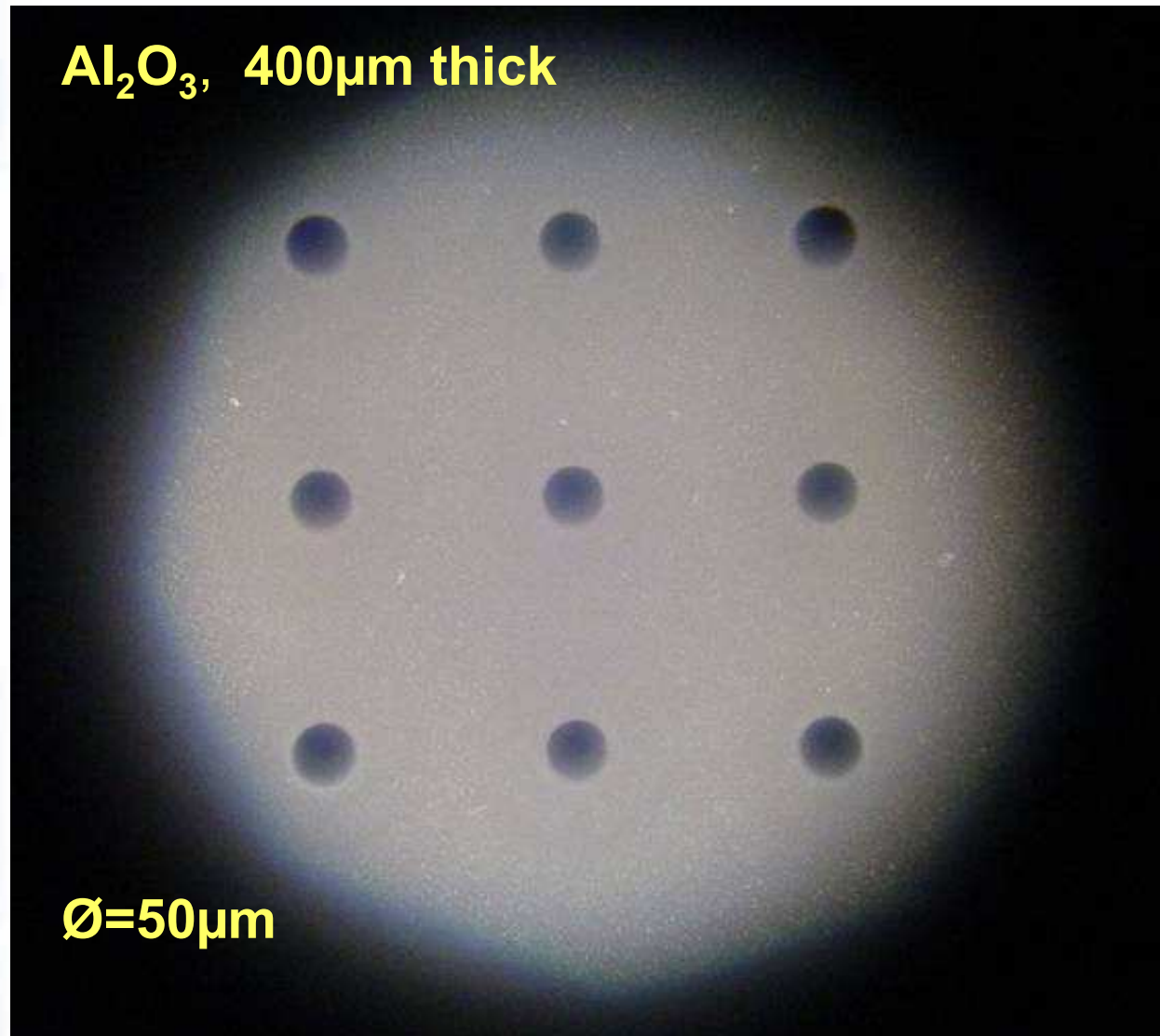
Thickness: 1 mm

1 sec / hole

HYPER-RAPID

1064nm, 50W

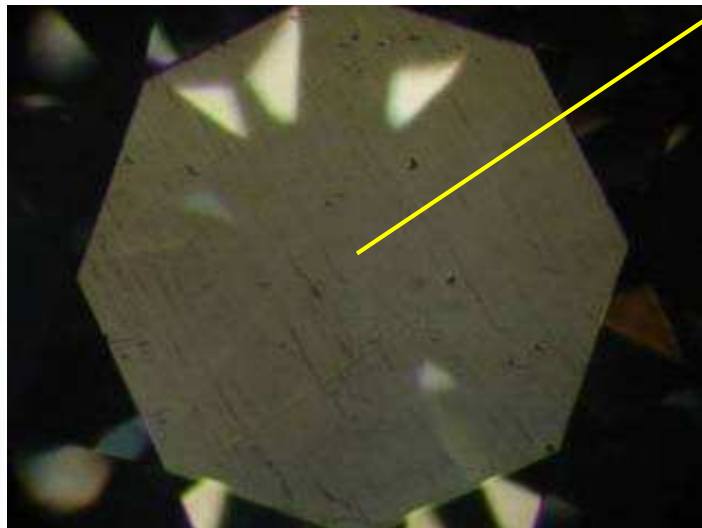
Drilling ceramics, test plates



~10% of cost !

**vs mechanical
drilling**

Diamant marking with ps-laser

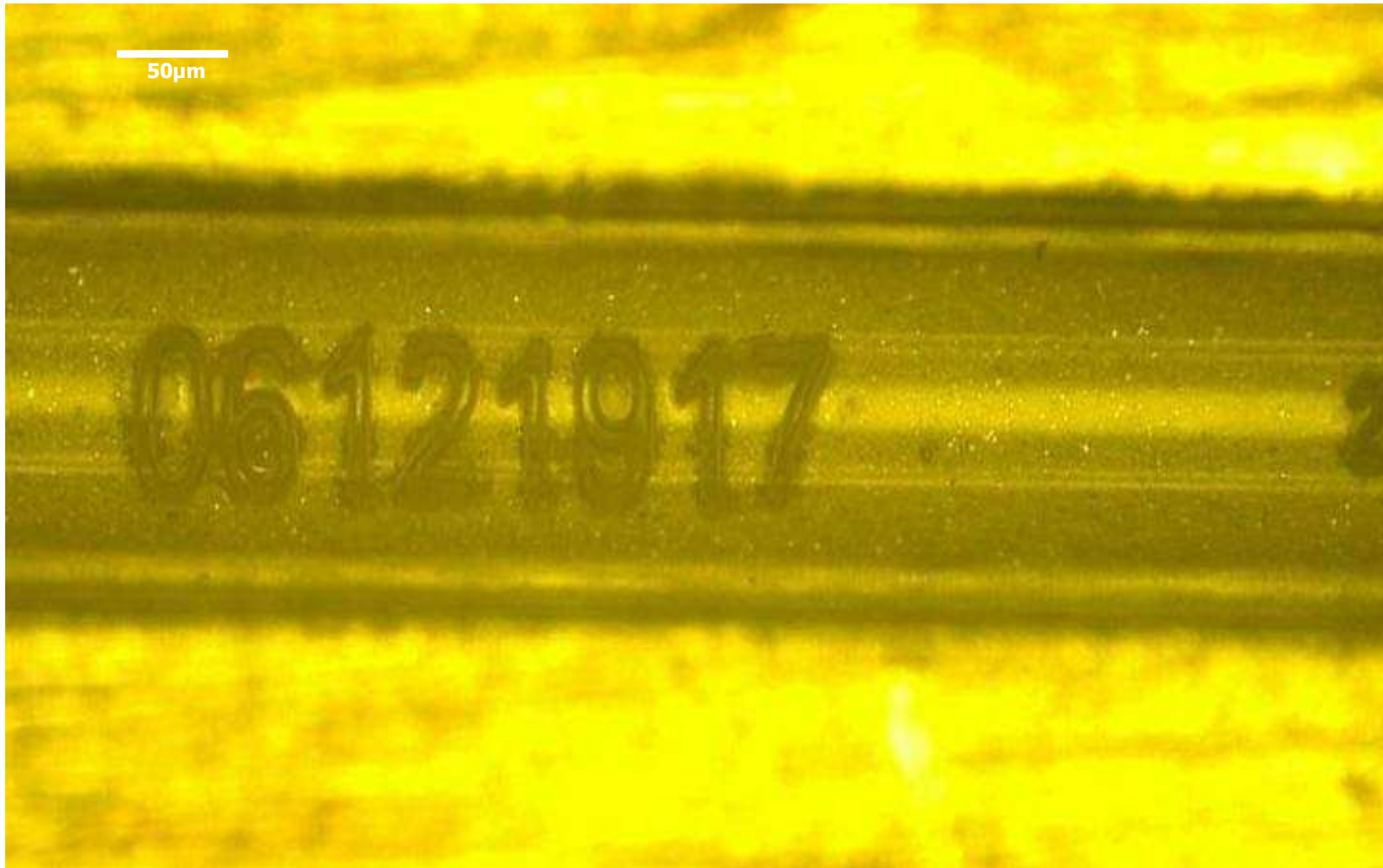


Line width ~ 5 μ m
Dimension < 500 μ m

$\lambda=355$ nm

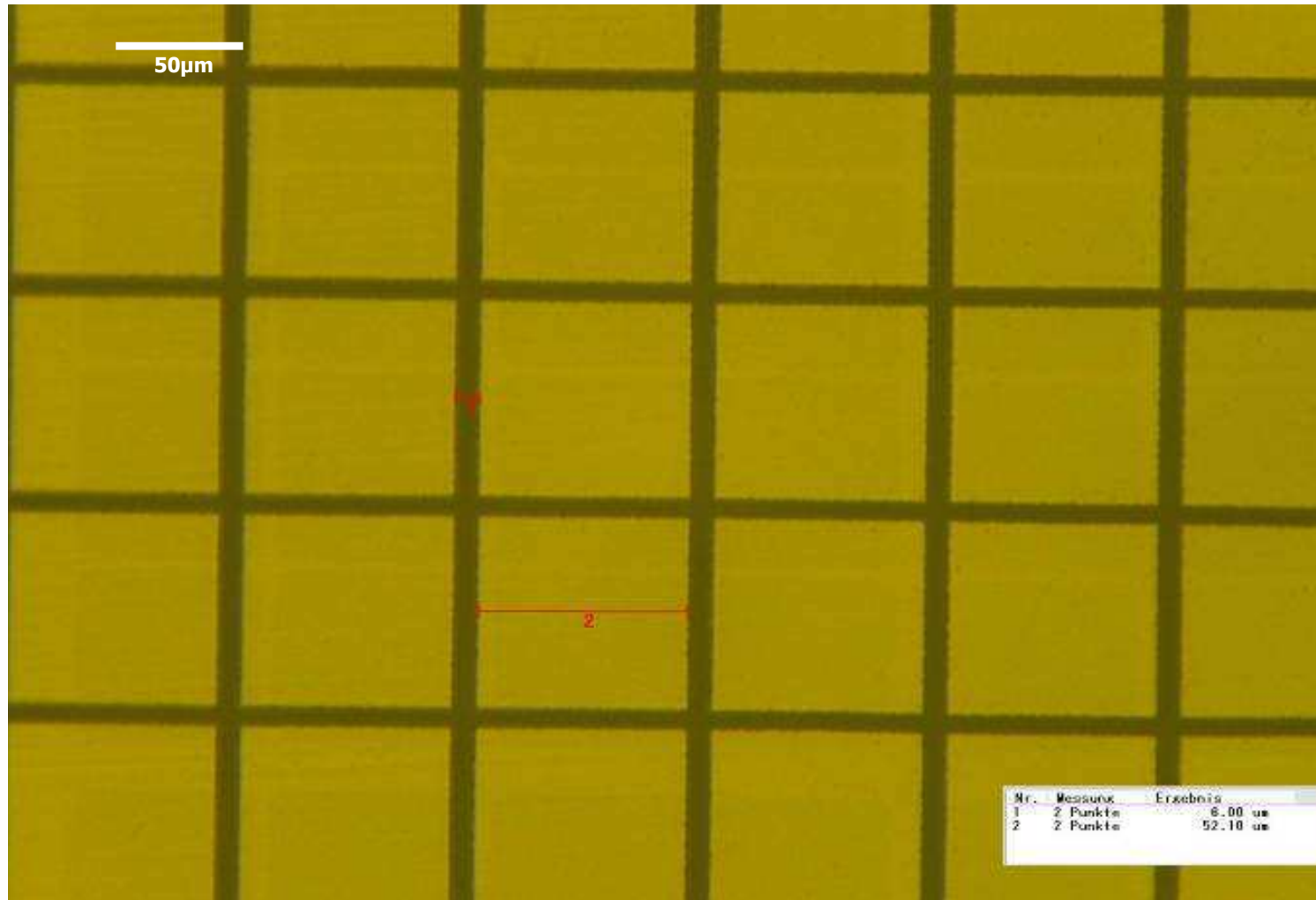
Marking of glass tubes

line 5 μ m wide, 400 characters/s; HYPER RAPID 50, 1064nm



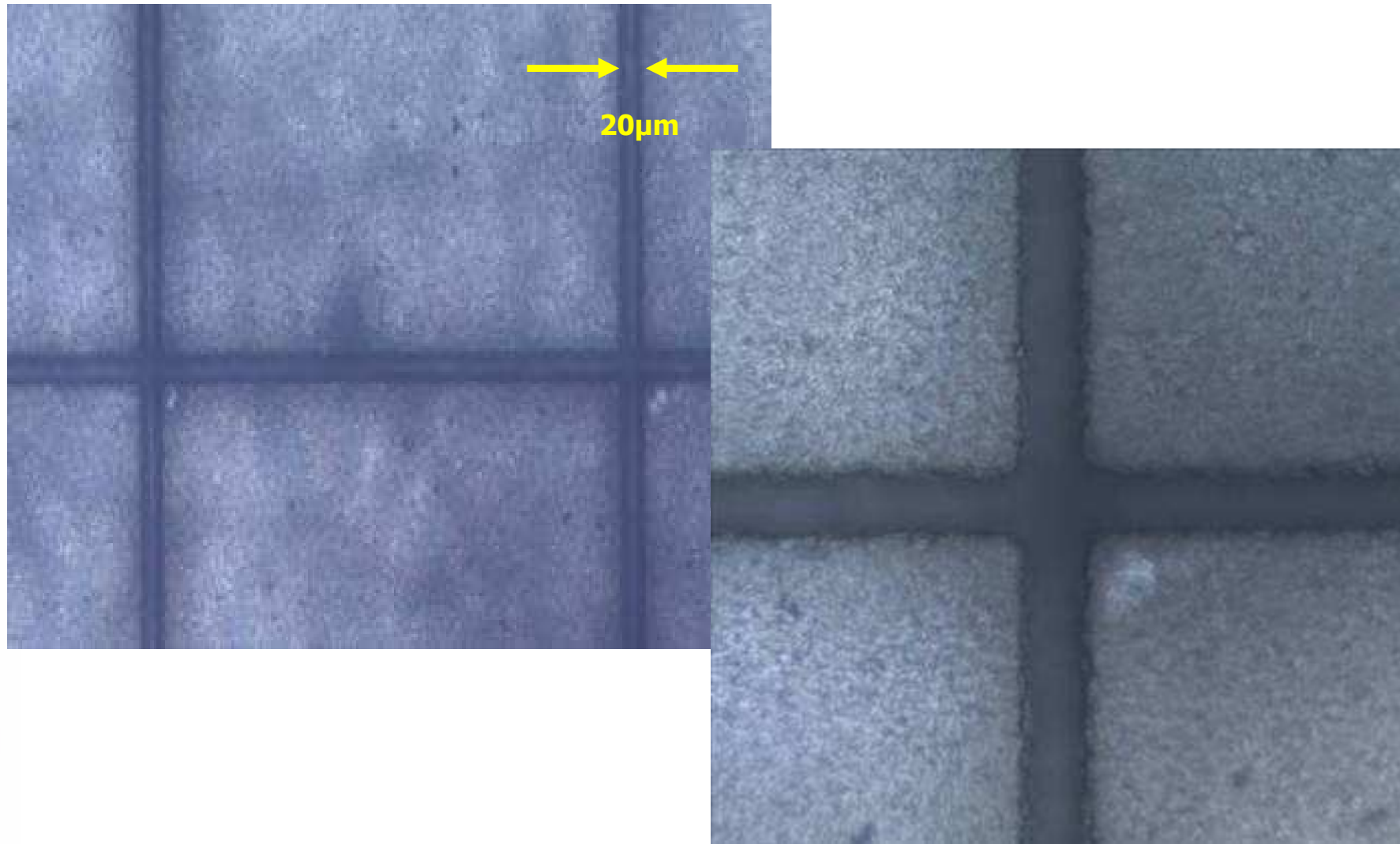
Borosilicate glass scribing

grooves 5 μ m wide, 1 μ m deep, 1m/s; HYPER RAPID 50, 1064nm



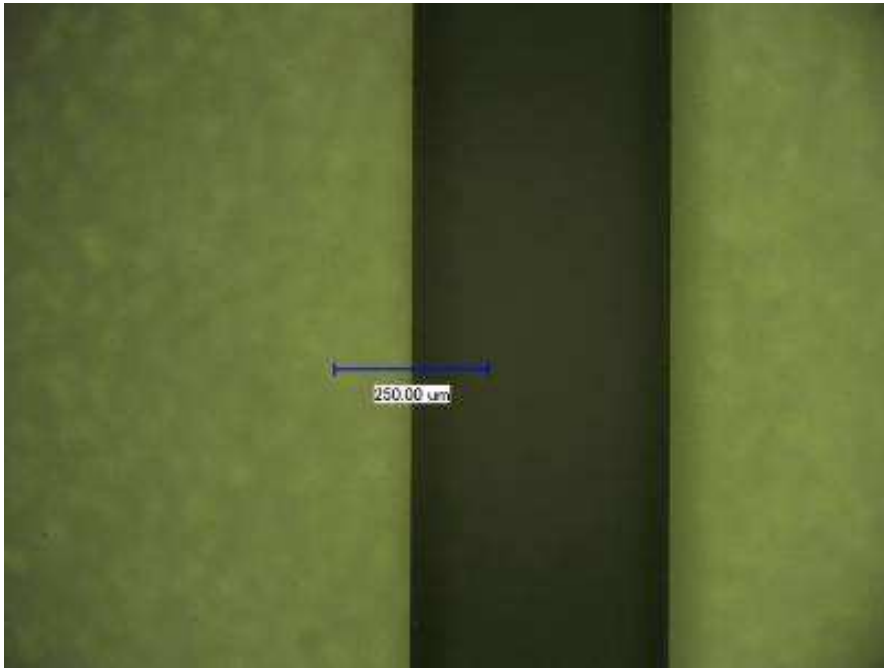
Scribing of glass

grooves 20 μ m wide, 40 μ m deep, 8cm/s; SUPER RAPID, 1064nm



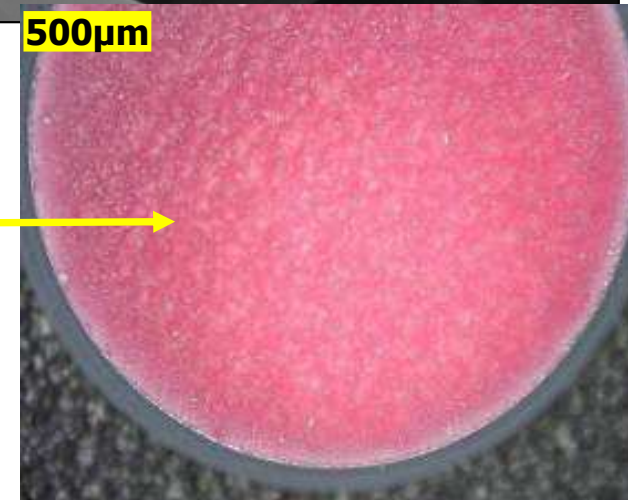
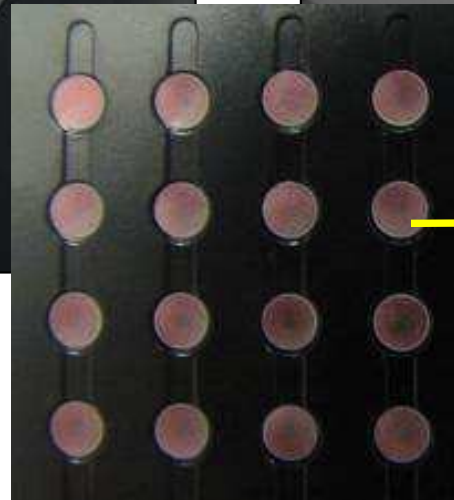
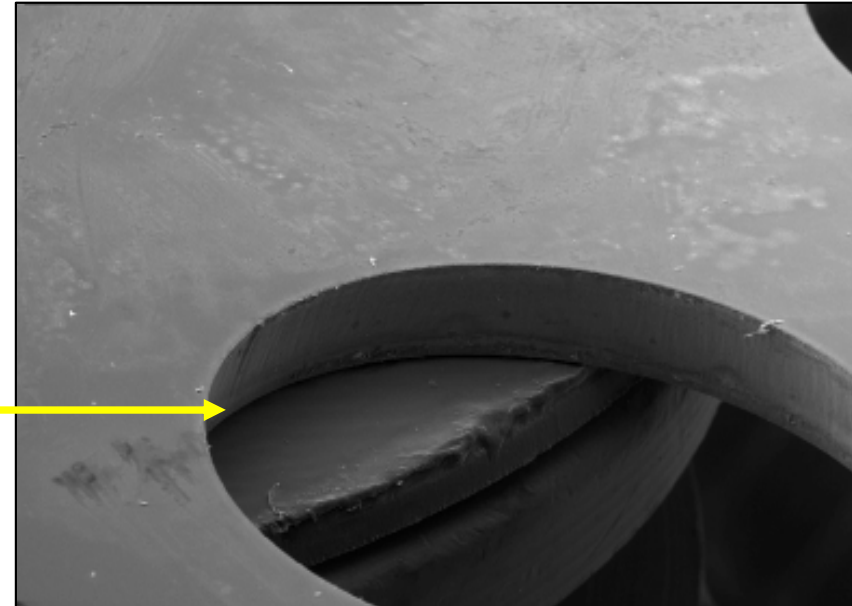
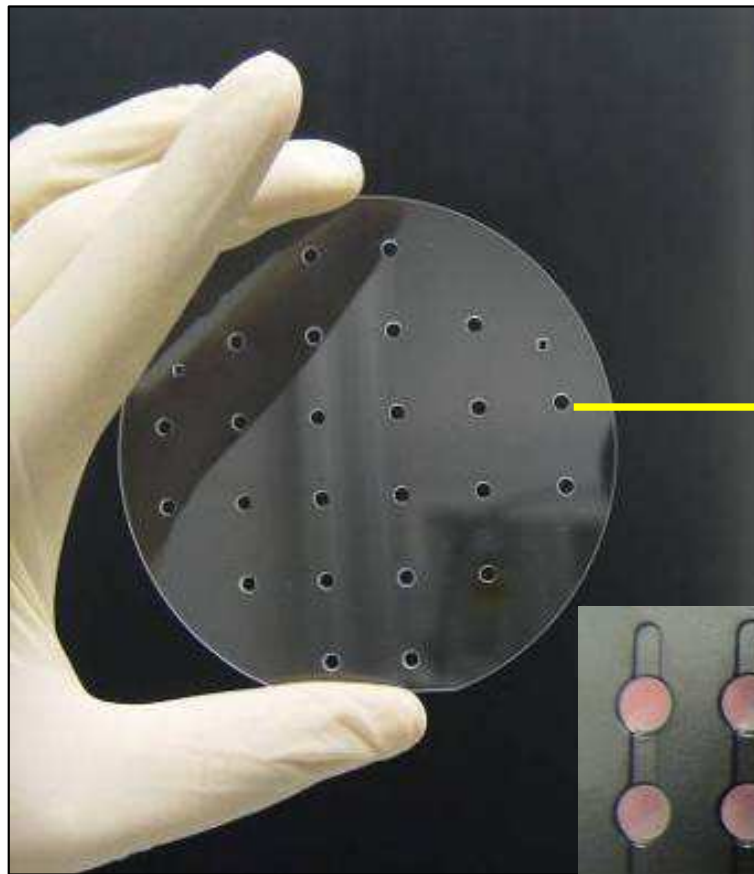
Borosilicate glass cutting

thickness 0.4 mm, 10mm/s, 40mm³/s ; HYPER RAPID 50, 1064nm



Borosilicate glass cutting

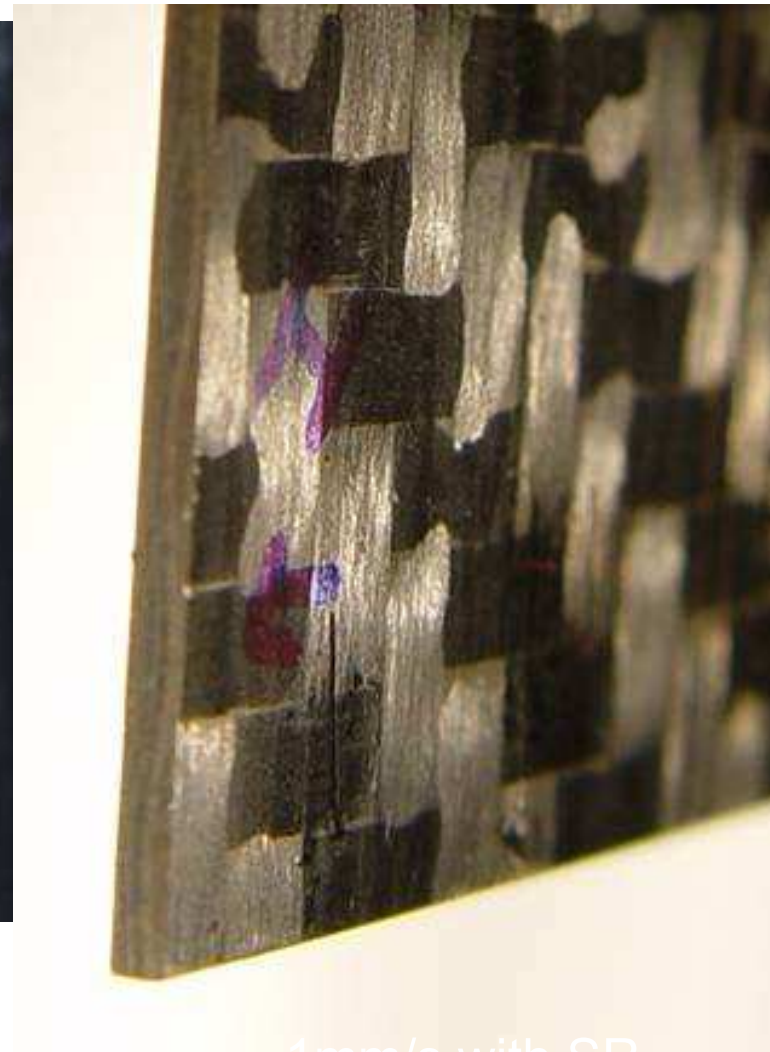
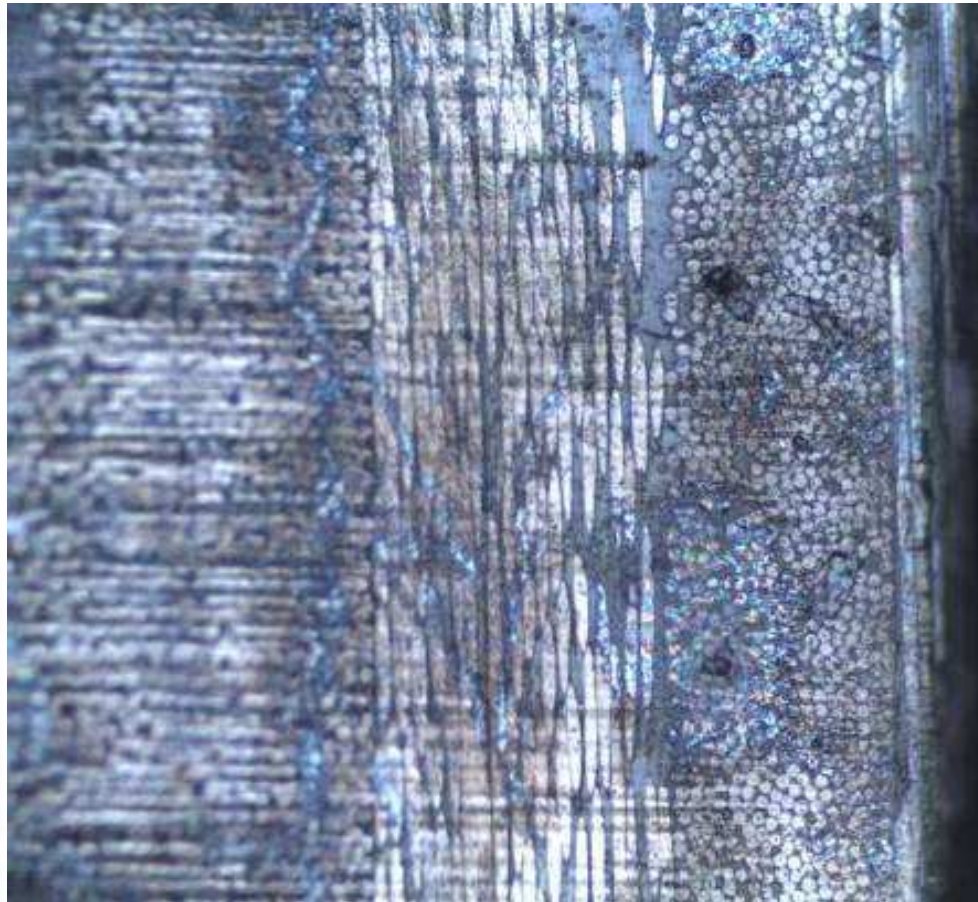
Glass wafer, 25 holes, $\text{\O} = 3 \text{ mm}$, $d = 0.5 \text{ mm}$



With dielectric coating
Diameter 3.5 mm
Thickness 150µm

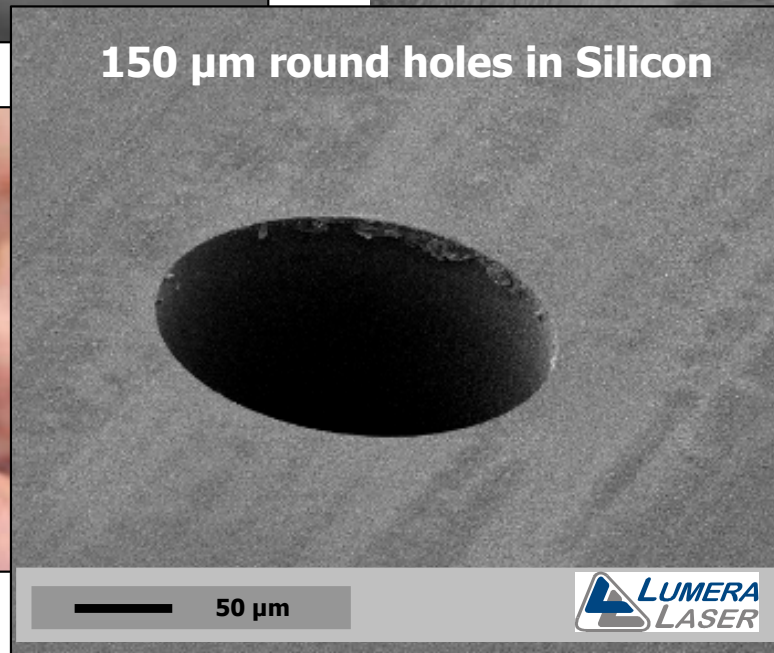
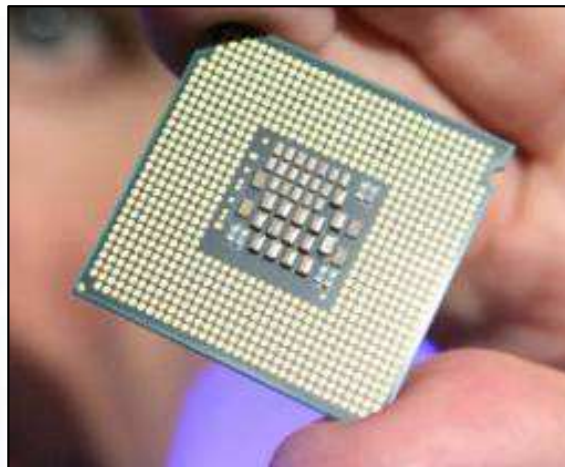
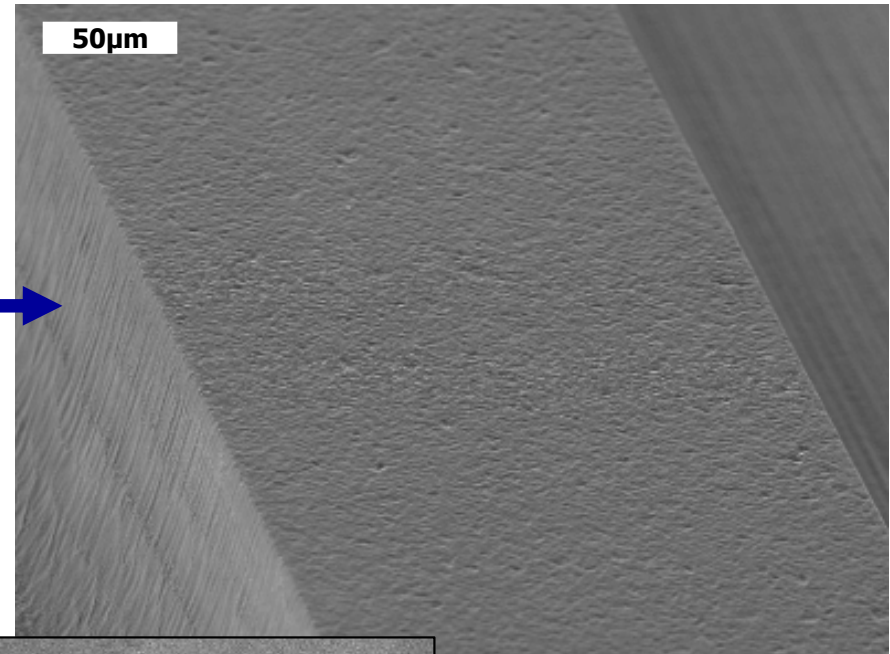
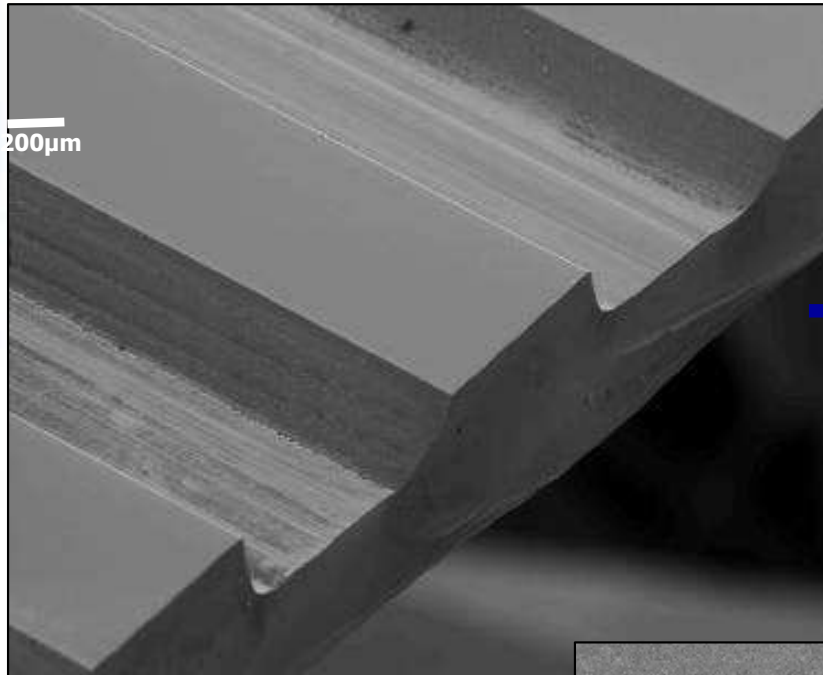
Cutting glass fibre composite

LUMERA LASER APPLICATION LAB:



1mm/s with SD

Grooves and holes in silicon



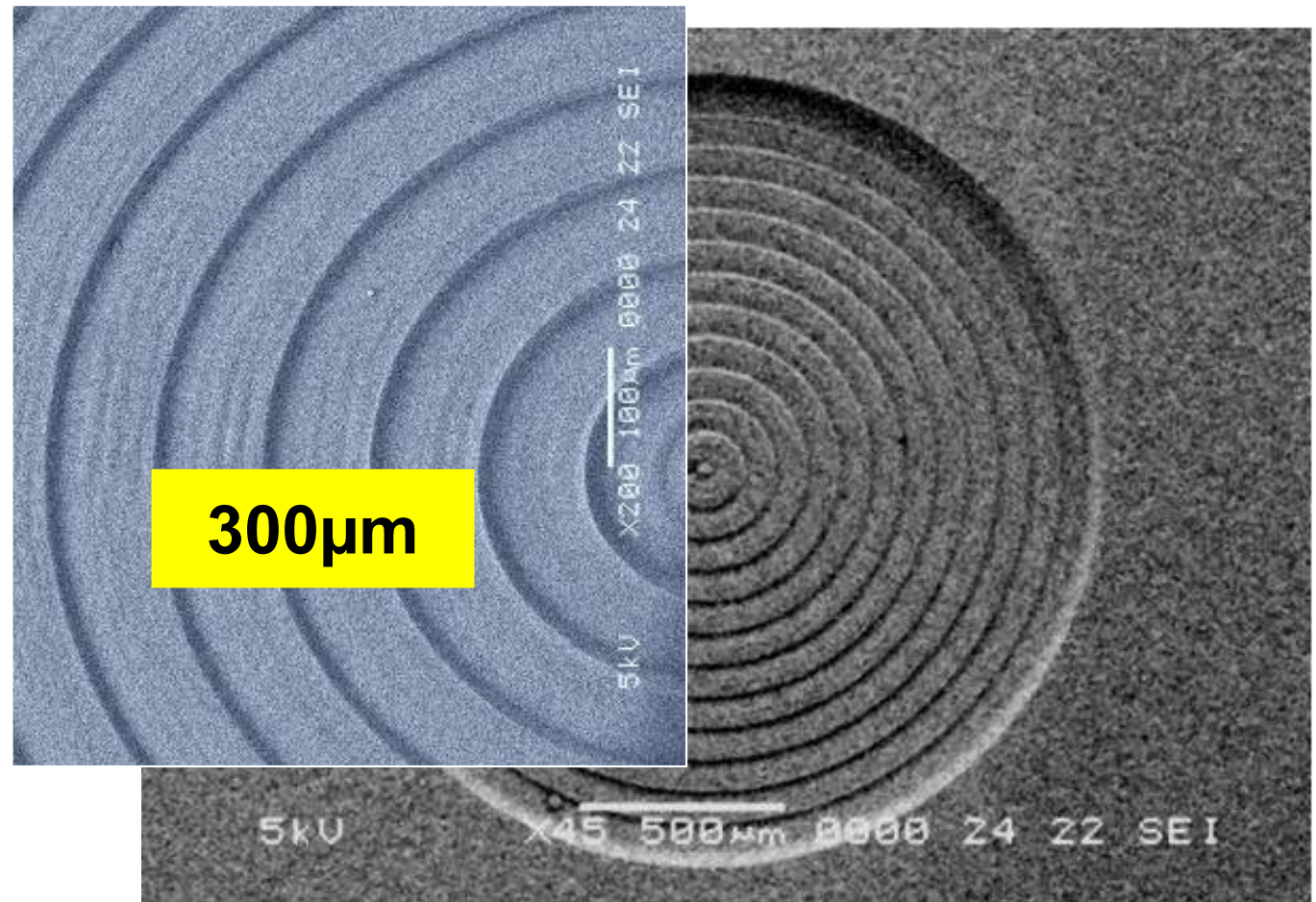
thickness 200µm
dia 150mm

5 holes/s

Surface structuring of sapphire

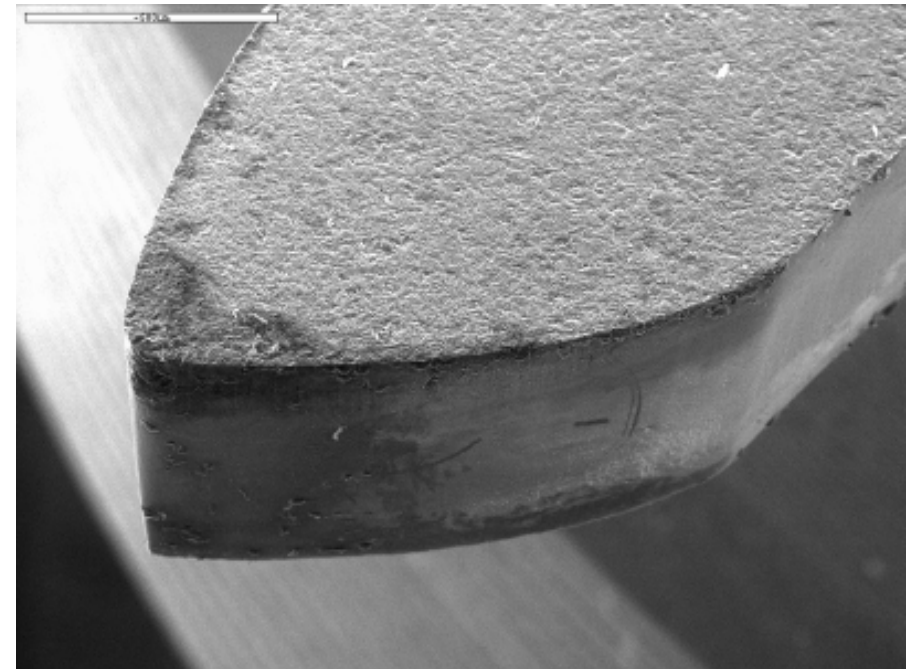
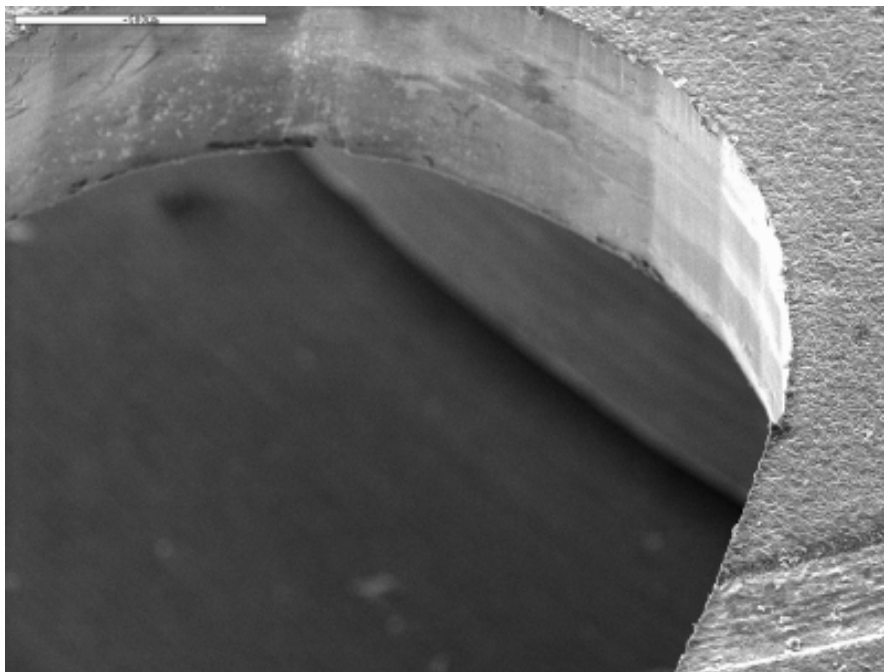
LUMERA LASER APPLICATION LAB:

**SAPPHIRE
steps
W100 μm x
D10 μm**



Sapphire cutting

thickness 0.5mm, 1mm/s cutting; HYPER RAPID 50, 355nm

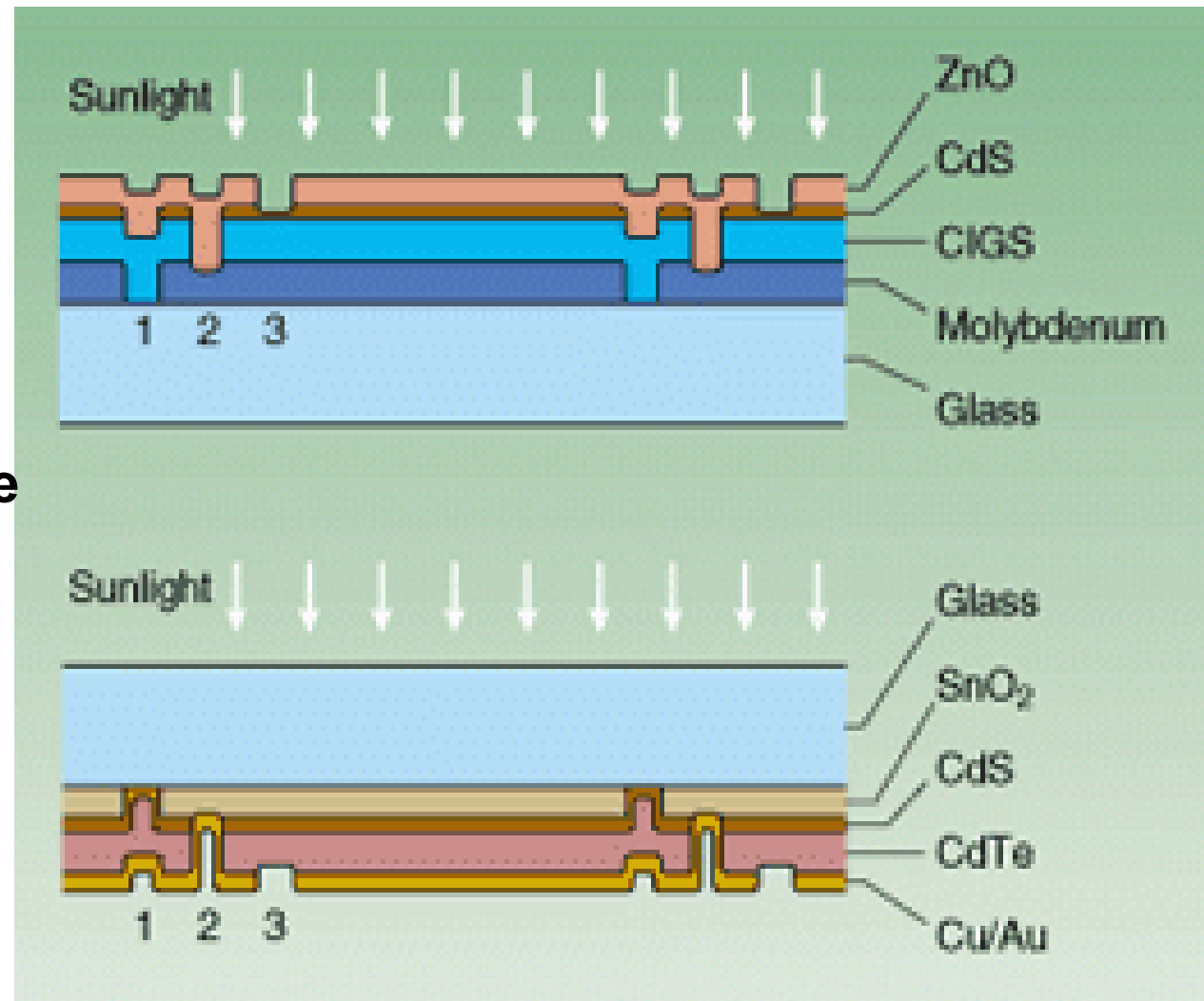


Thin Film Laser Scribing

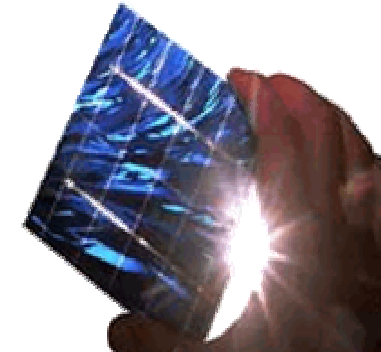
mechanical scribes for P2 and P3 due to melting of molybdenum layer when using ns IR or green lasers.

Picosecond lasers are under evaluation for application in P2 and P3 scribes.

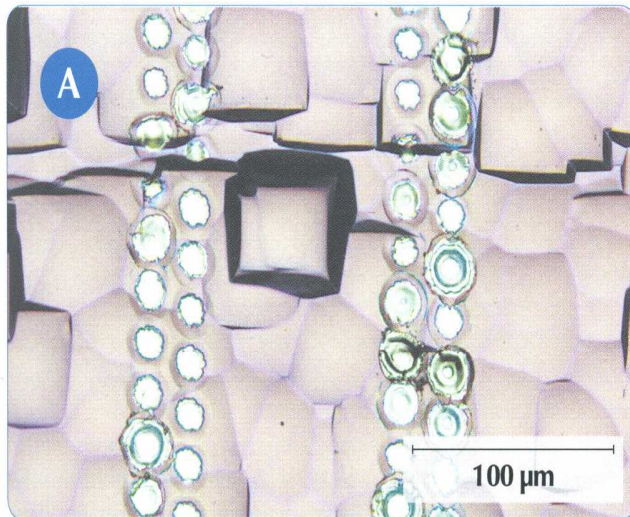
A. Compaan,
Laser Focus World



Ablation of SiO_2 -or SiN-layer on Si; dia $50\mu\text{m}$



$\tau \sim 30\text{ns}$



$\tau \sim 10\text{ps}$

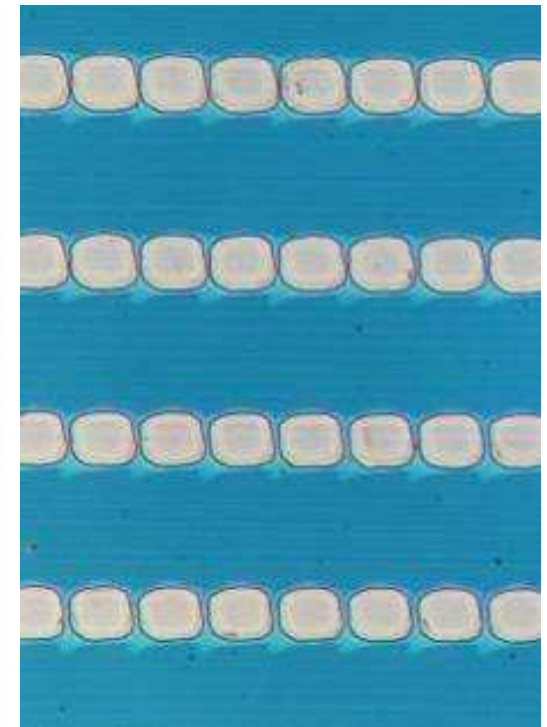
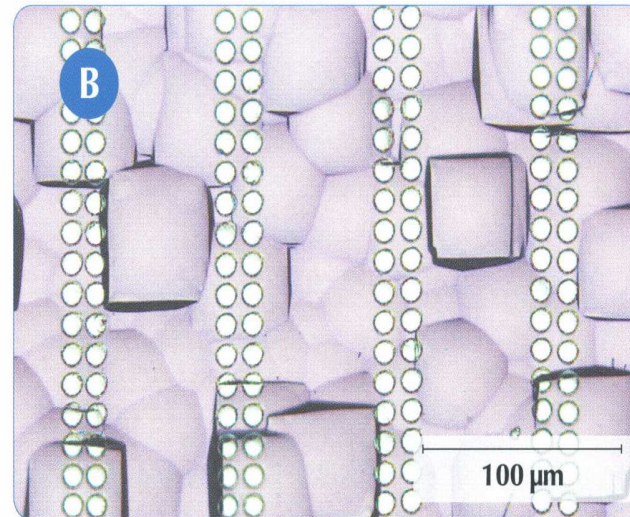


Abb. 27: Lichtmikroskopische Aufnahme einer mit SiO_2 bedeckten Siliciumoberfläche nach lokaler Laserablation mit Hilfe A) eines Nd:YVO₄ Lasers ($\lambda=355\text{ nm}$) mit einer Pulsdauer von ca. 30 ns und B) eines Nd:YVO₄ Ultrakurzpulslasers ($\lambda=532\text{ nm}$) mit einer Pulsdauer von ca. 10 ps.

Fig. 27: Light optical microscope picture of a SiO_2 -covered silicon surface after local laser ablation using A) a Nd:YVO₄ laser ($\lambda=355\text{ nm}$) with a pulse duration of about 30 ns and B) a Nd:YVO₄ ultra-short pulse laser ($\lambda=532\text{ nm}$) with a pulse duration of about 10 ps.

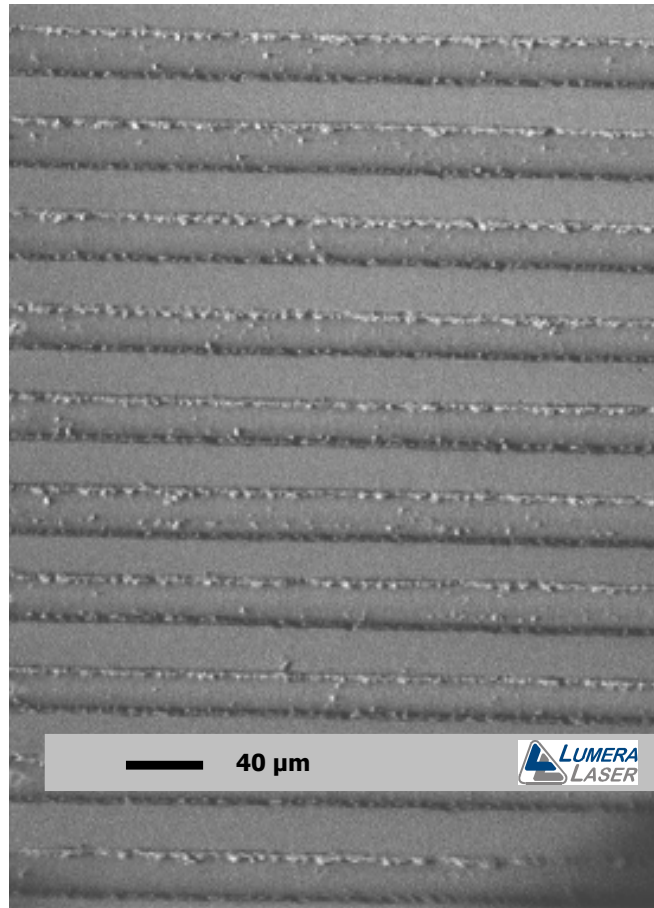
Source: ISFH

HYPER-RAPID: 1mio holes / s

Transparent Conductive Oxide

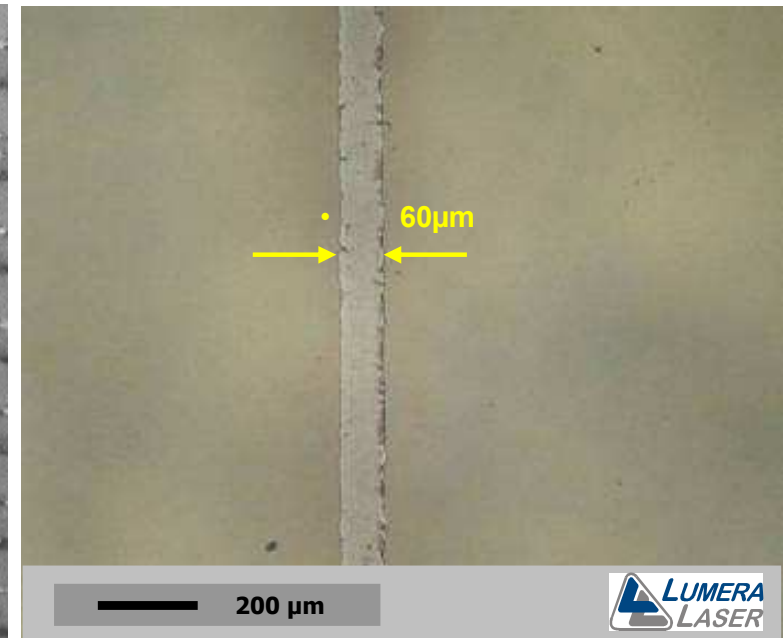


TCO on plastic

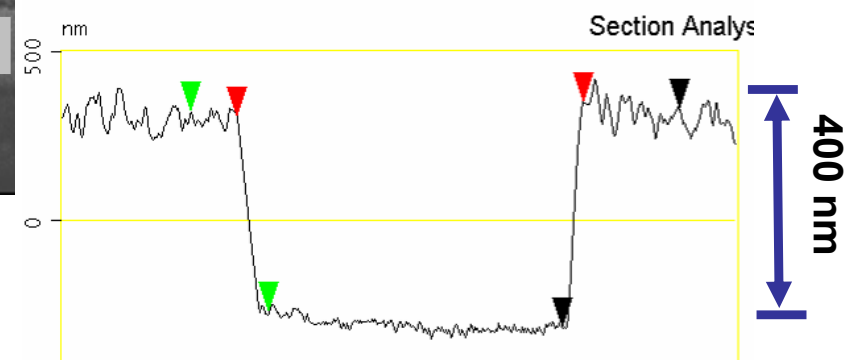


width=20μm
thickness: 500nm

TCO on glass

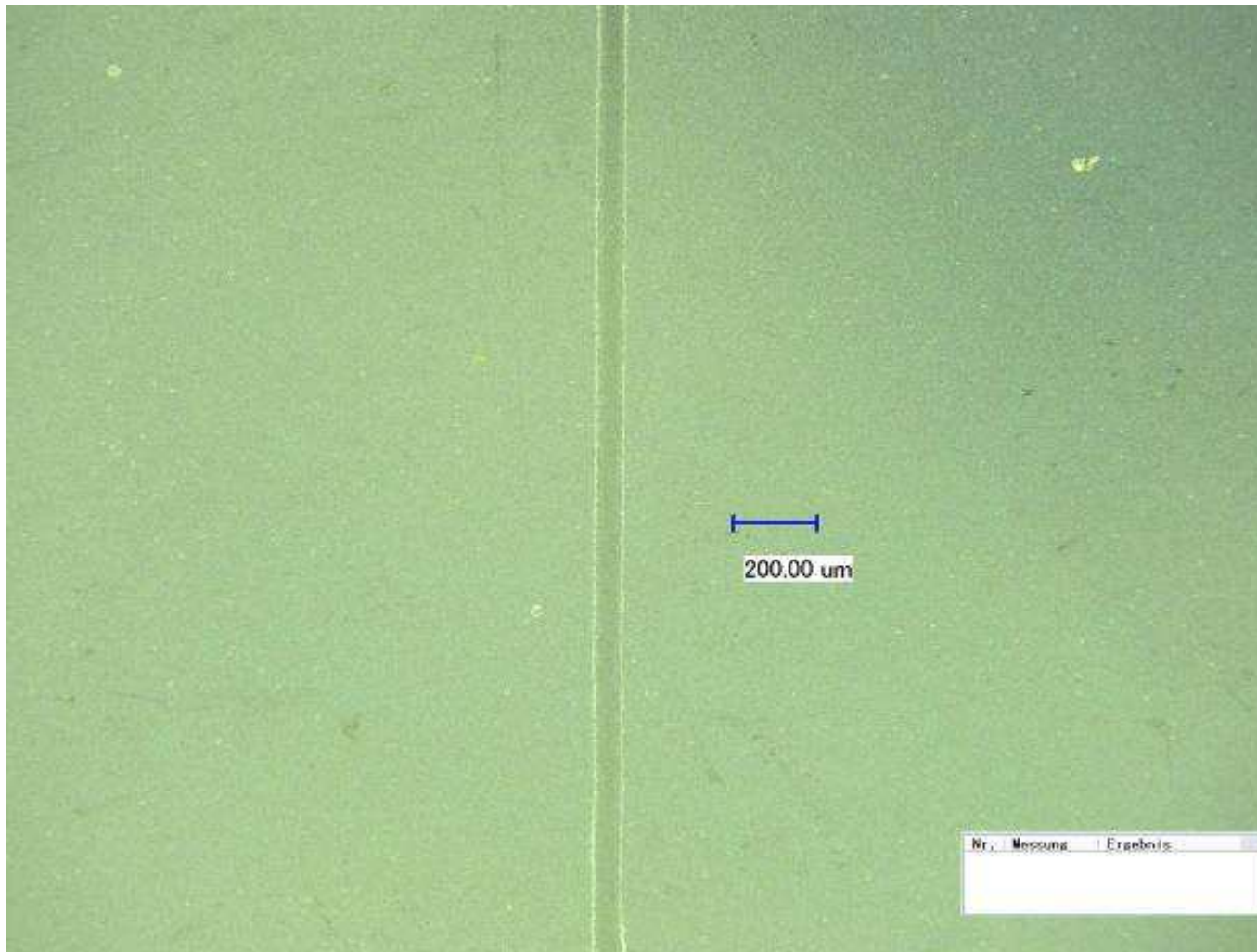


Cursor Marker Spectrum Zoom Center Line Of



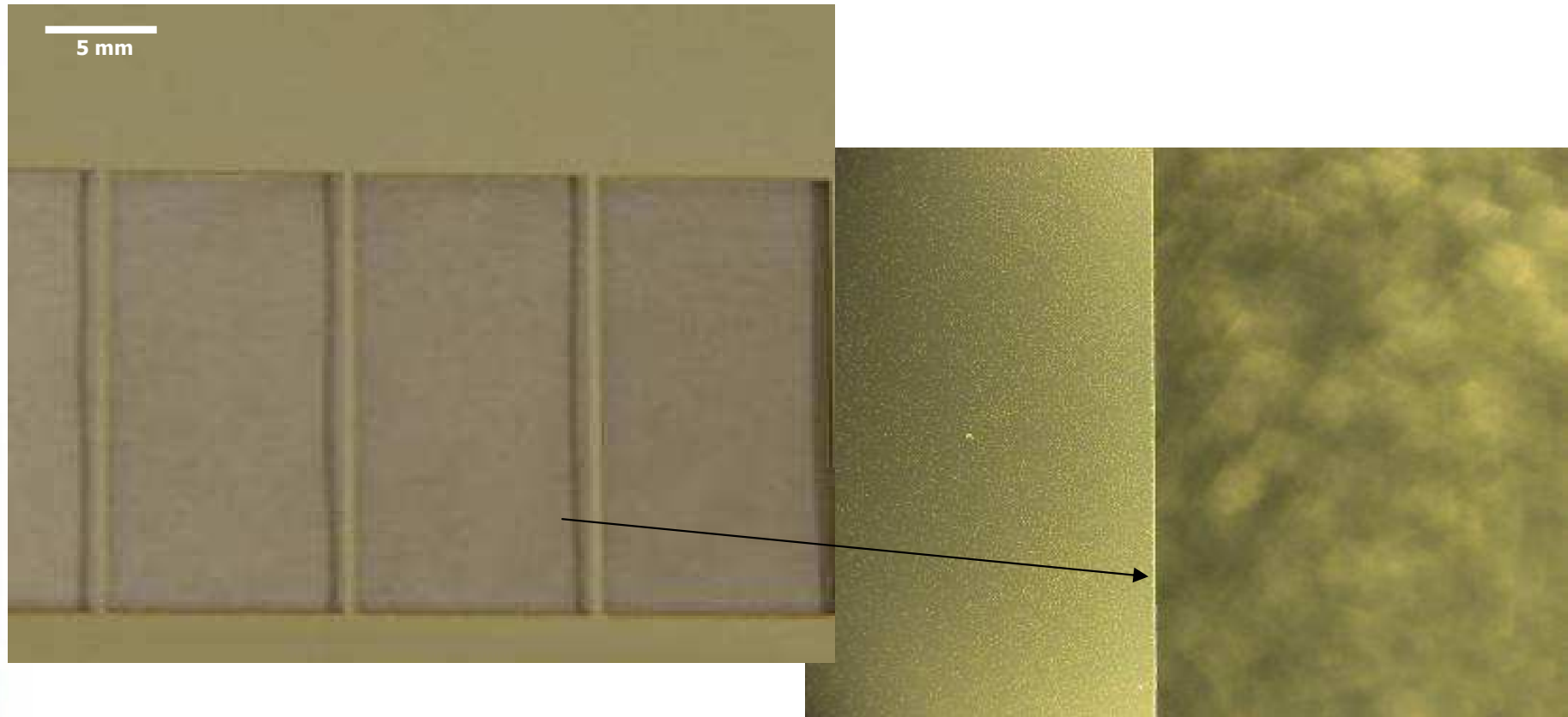
ITO removal on glass

lines 50 μ m wide, 200nm deep, >5m/s; HYPER RAPID 50, 1064nm

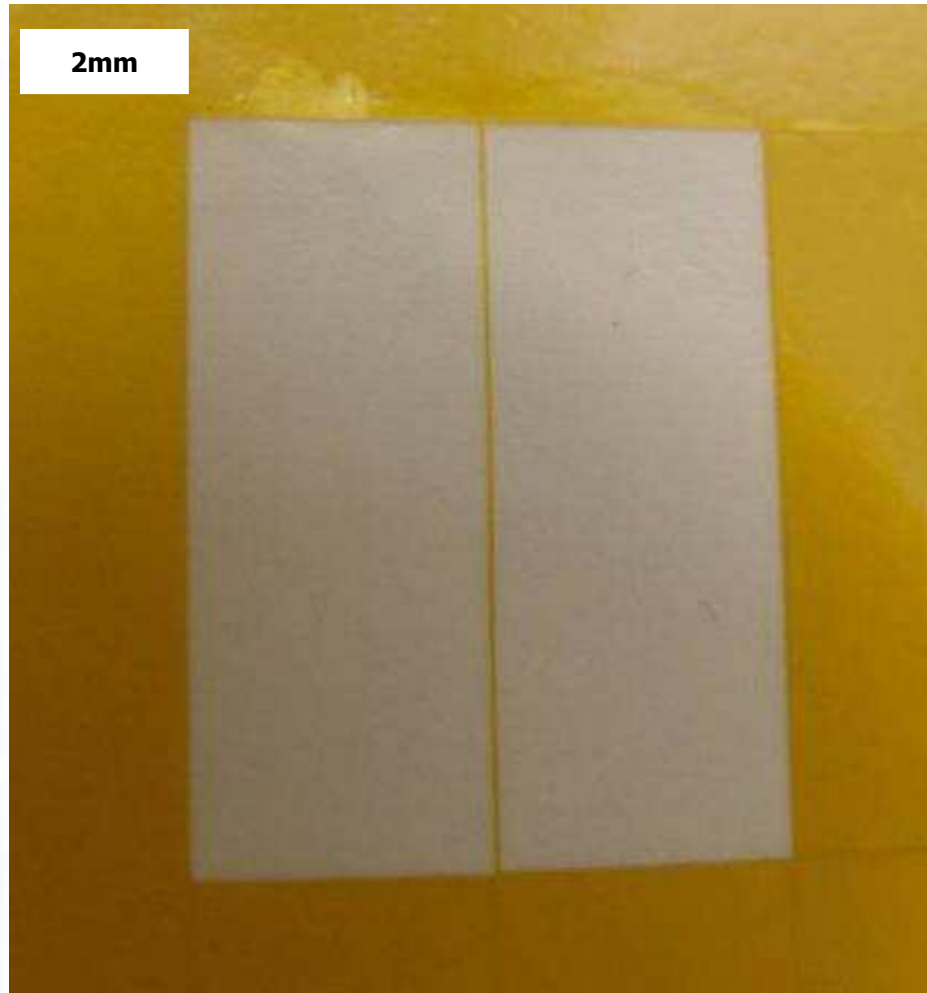


Removing metal layer on glass

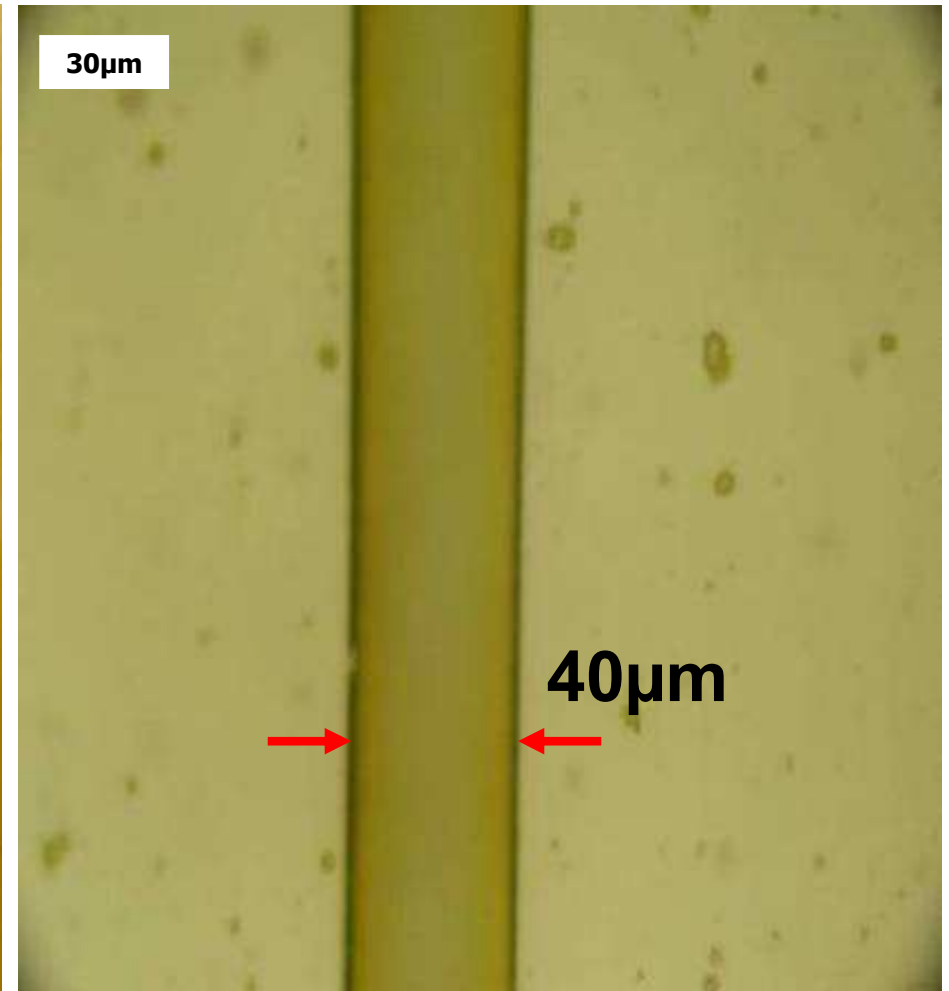
200nm thick metal coating; 1cm²/s; RAPID, 1064nm



30 μ m capton on paper

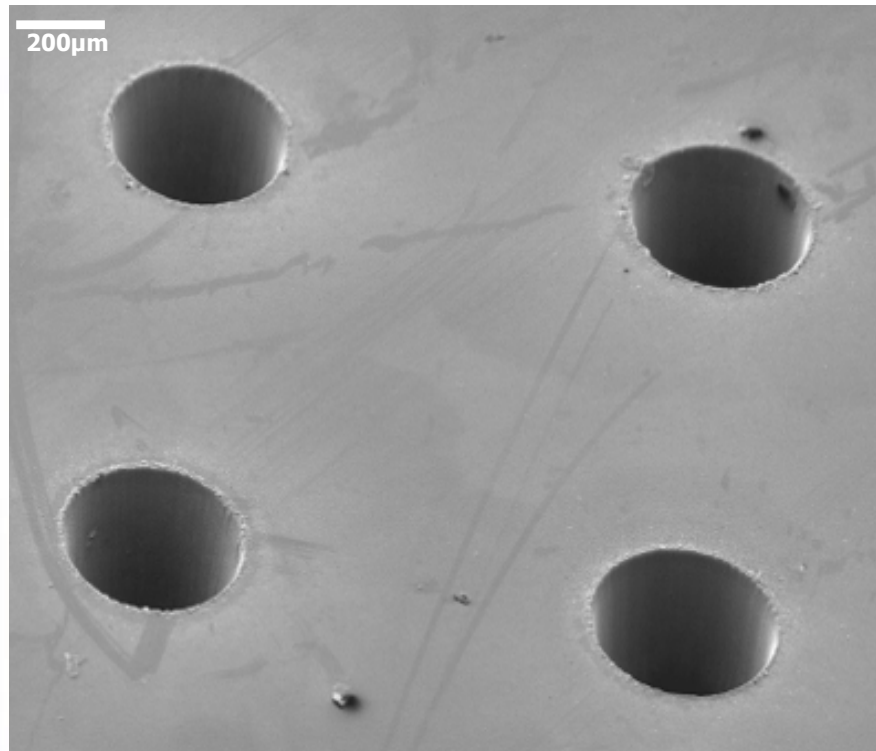


Grooves in capton



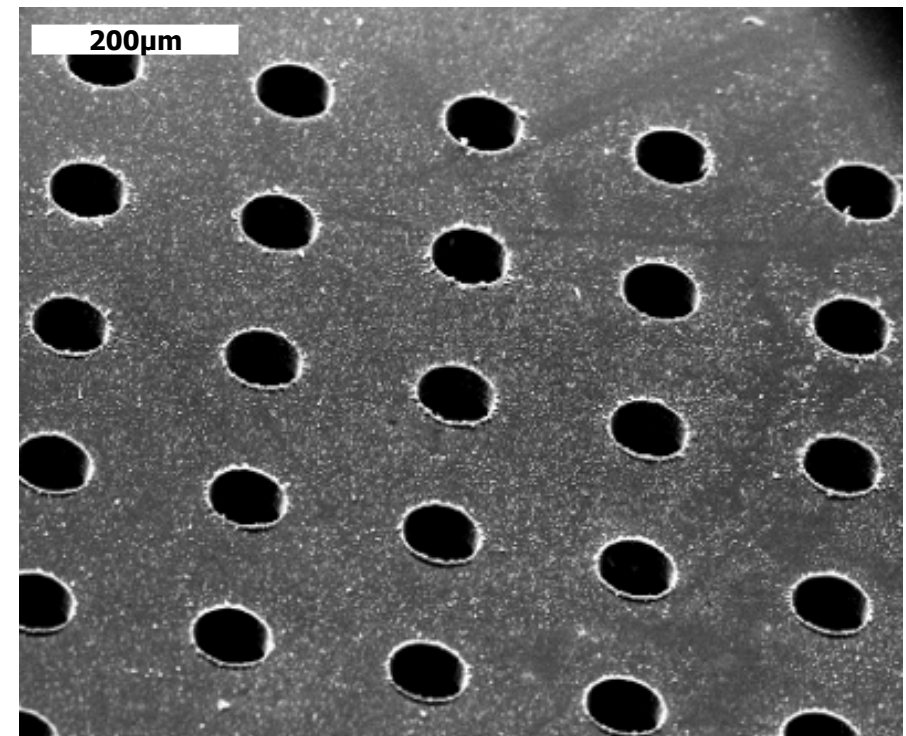
..thermally sensitive materials

PET



$\text{Ø}=250\mu\text{m}$
thickness: 350µm

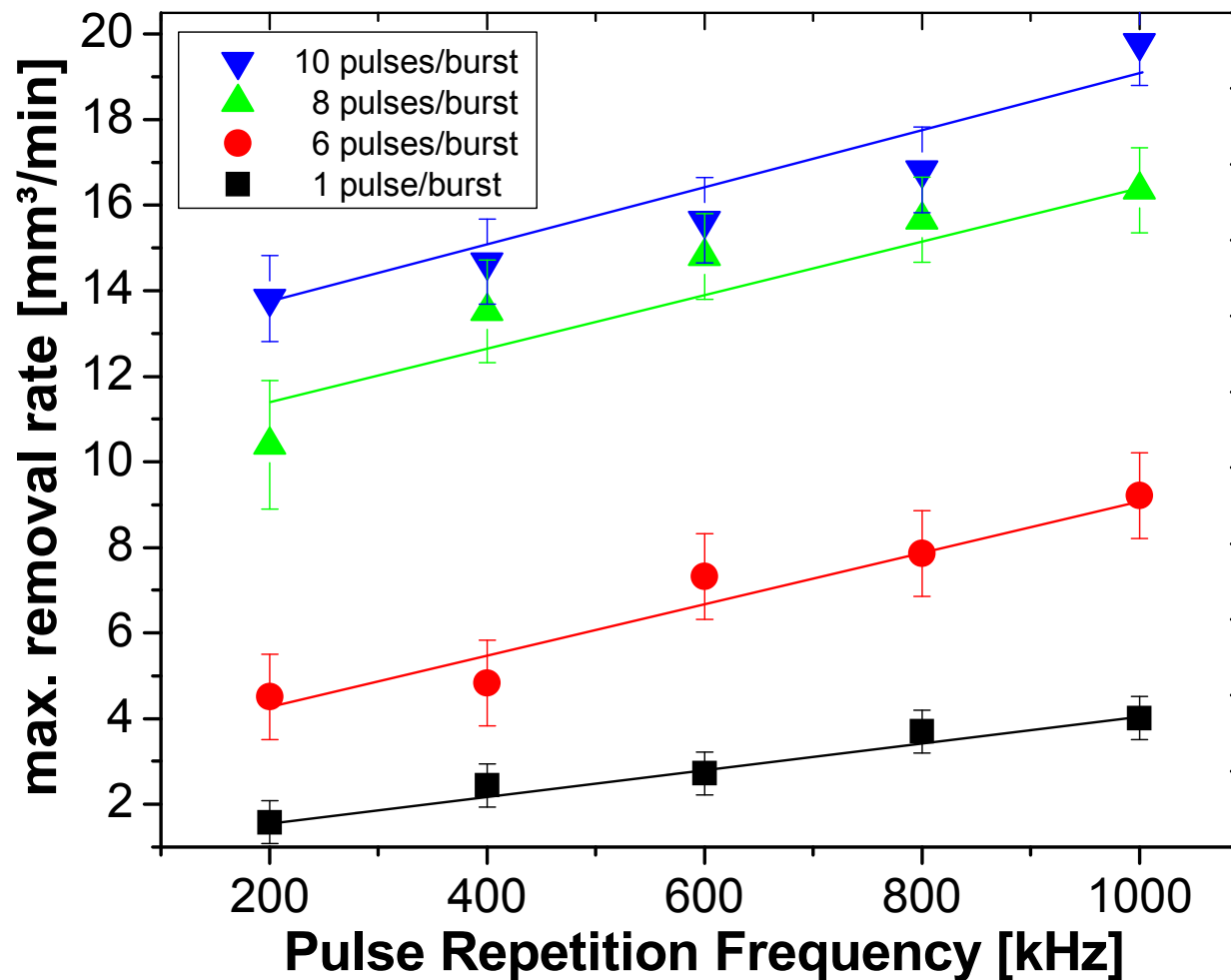
Nylon



$\text{Ø}=100\mu\text{m}$
thickness: 50µm

Burst Machining of Tungsten Carbide

Hyper Rapid 50, 1064 nm, constant average power of 50W @1MHz

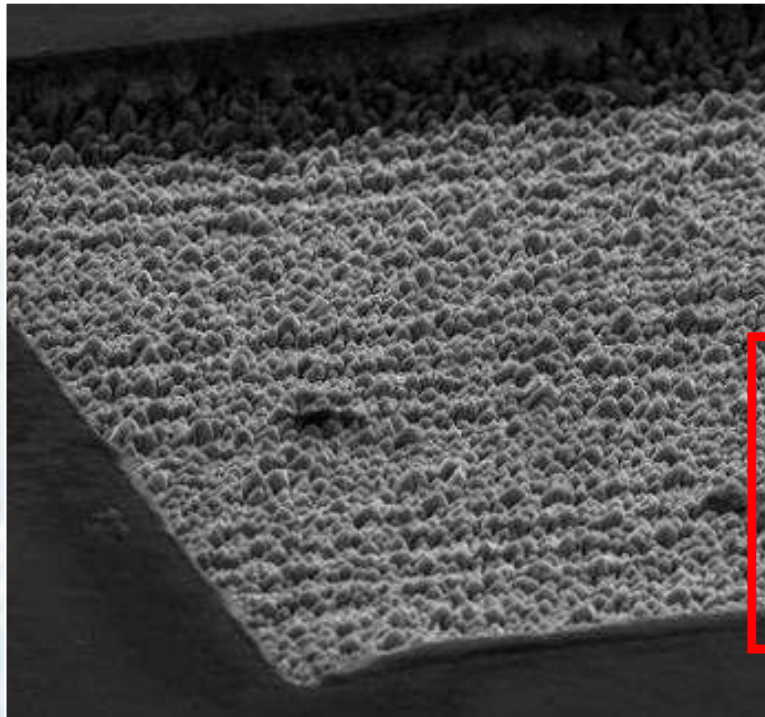


- high rep. rate + burst: 14x removal rate

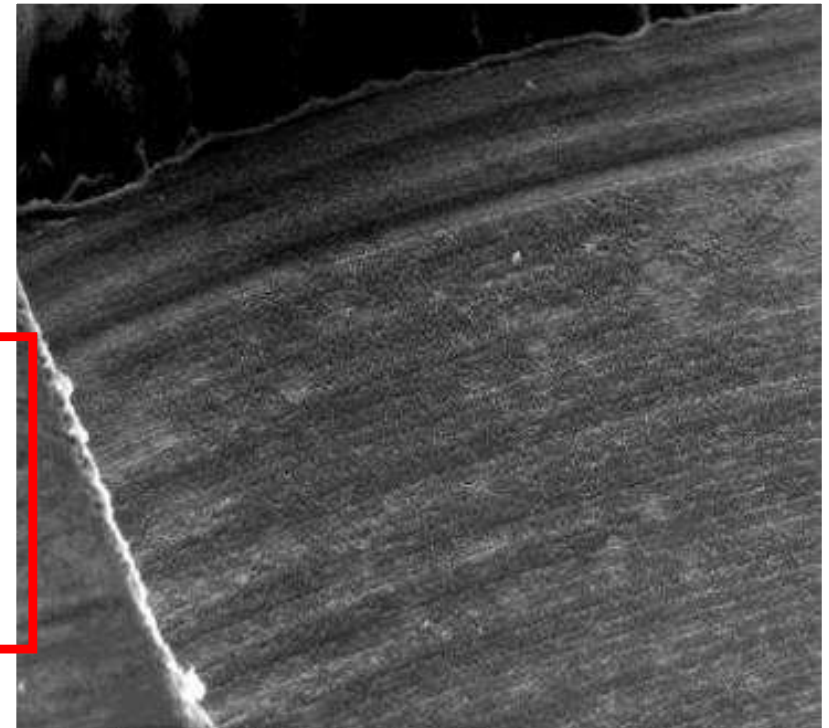
Burst Mode: Quality

Burst mode increases removal rate & surface quality, e.g. on Si:

1 pulse



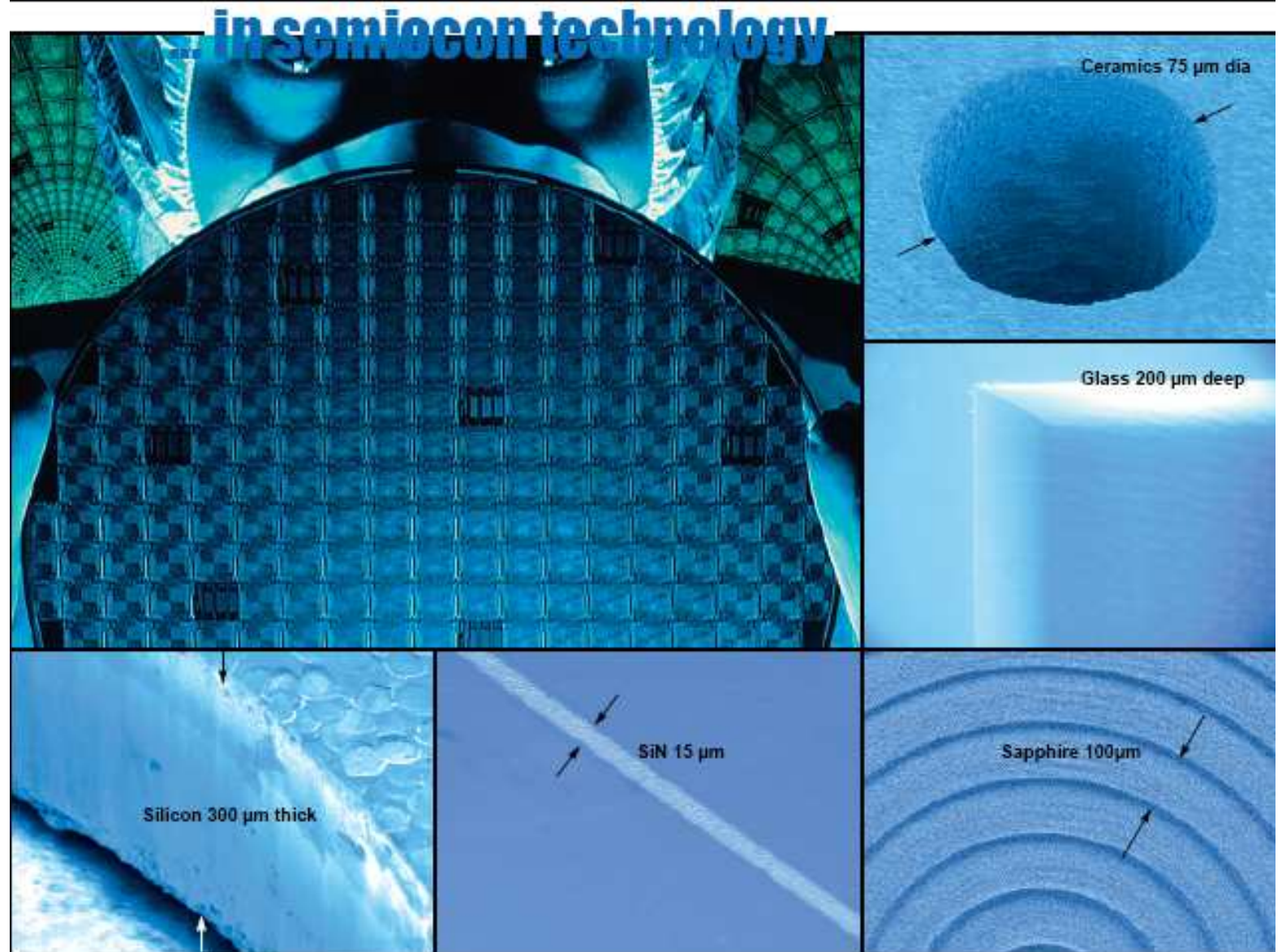
5 pulses (20 ns separation)



8x
→
removal rate

Applications and target industries

vias,
3D TSV,
MEMS
dicing,
memory
repair,
machining
difficult
materials
like
ceramics,
structuring
organic
coatings

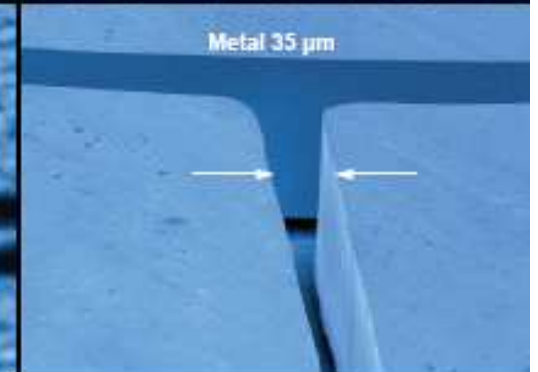
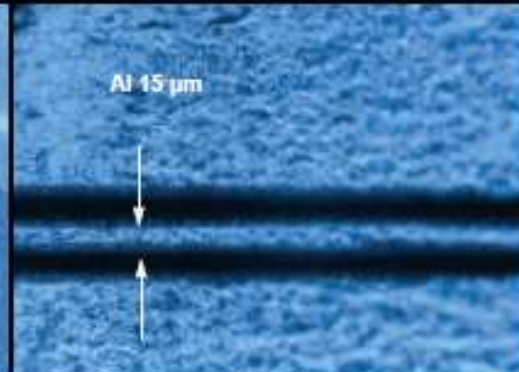
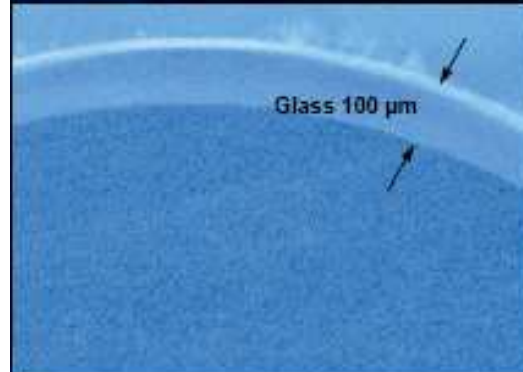
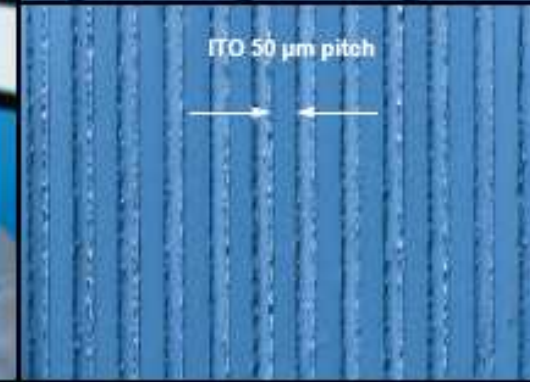
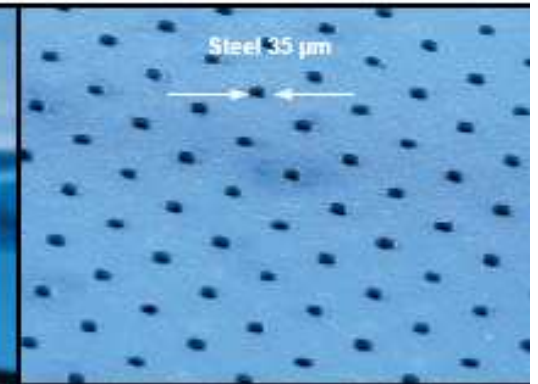


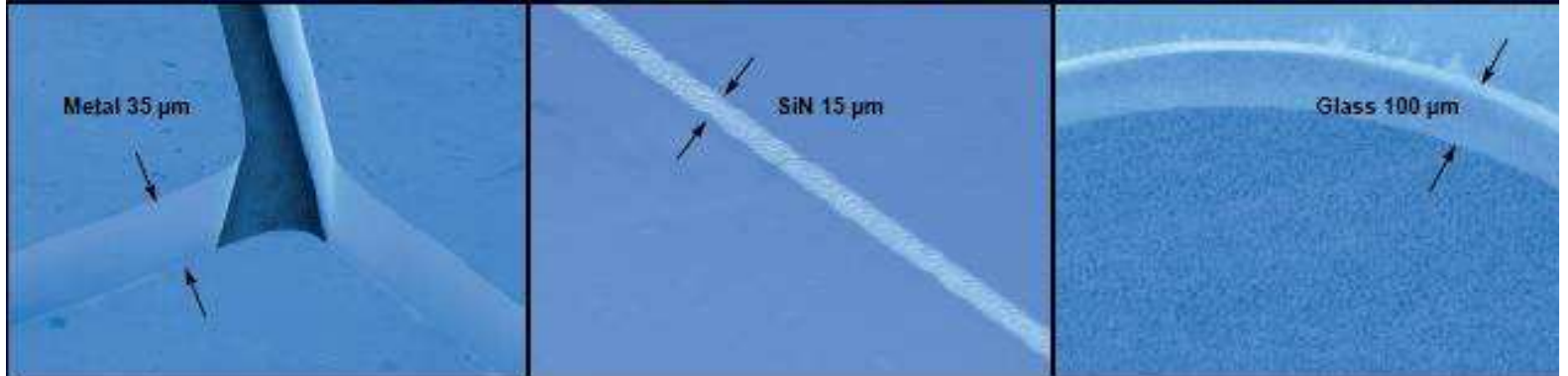
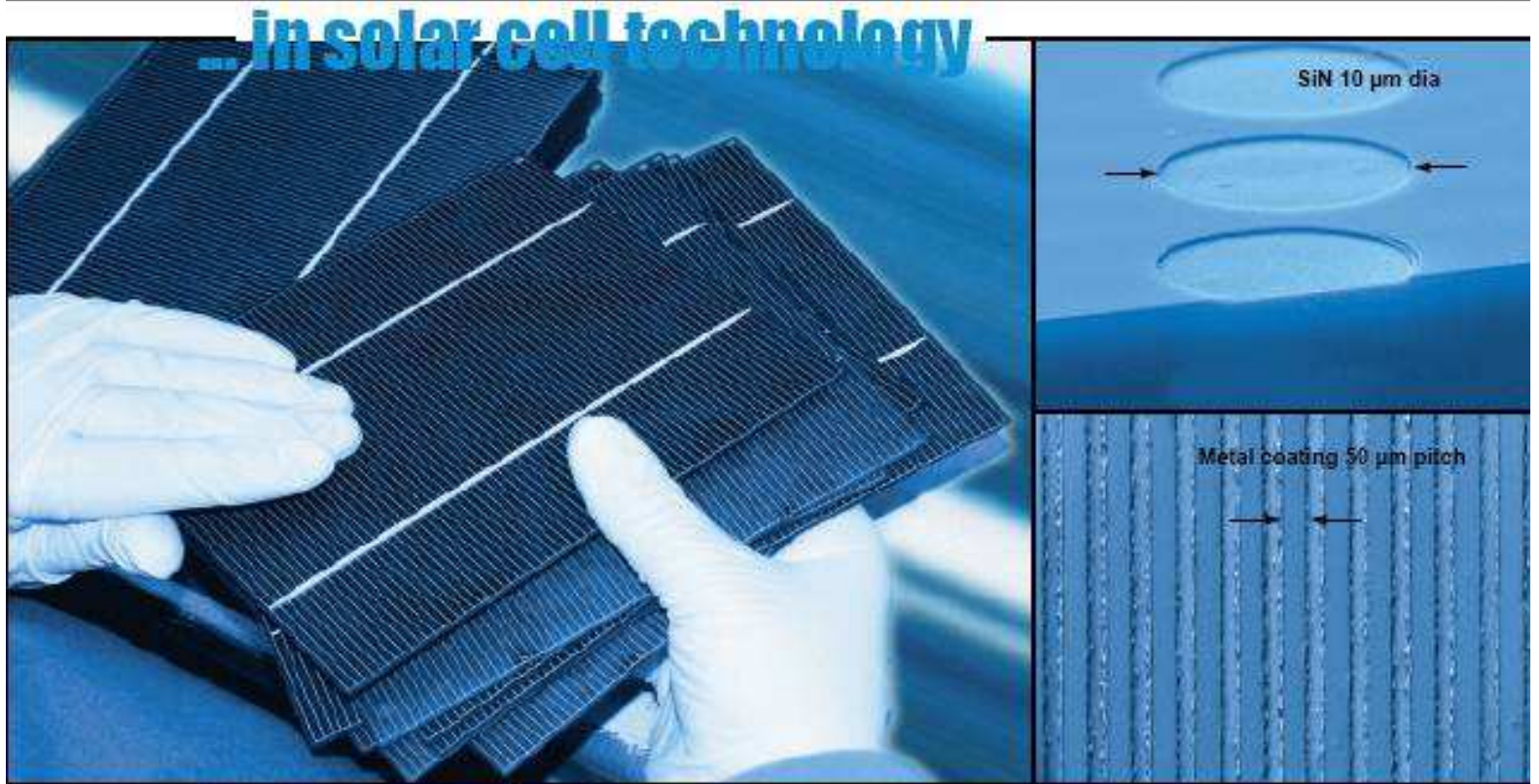
industrial ps laser micromachining

... in display technology

... in display technology

scribing or
welding
glass,
structuring
and
repairing
masks,
structuring
ITO/AZO
and
similar
coatings





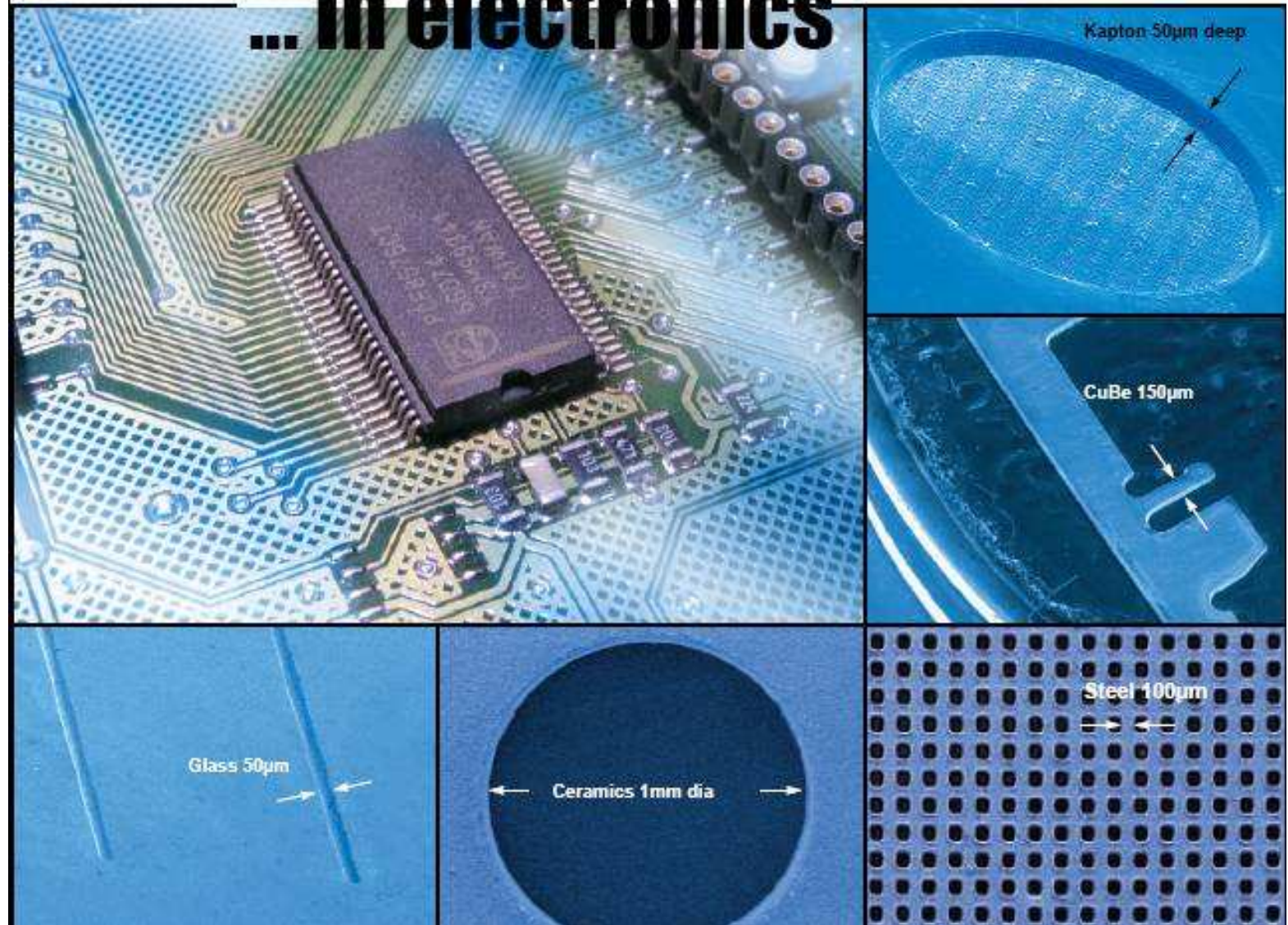
ablation of dielectric coatings, doping selective emitters direct writing, drilling vias, EWT-holes, cutting thin material

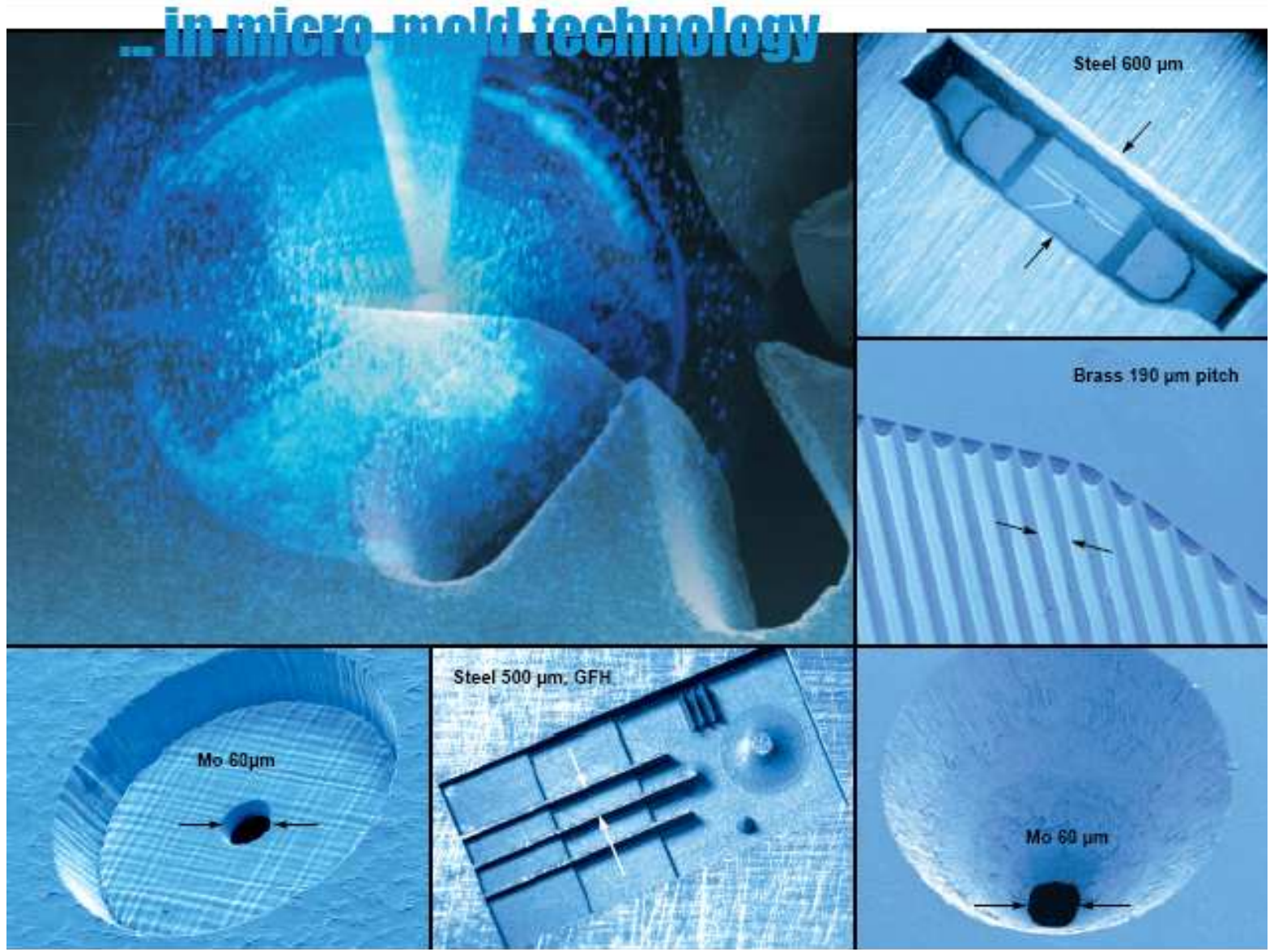
industrial ps laser micromachining

... in electronics

... in electronics

via
drilling,
cutting
flex
boards,
trimming
organics,
micro-
parts
like
apertures

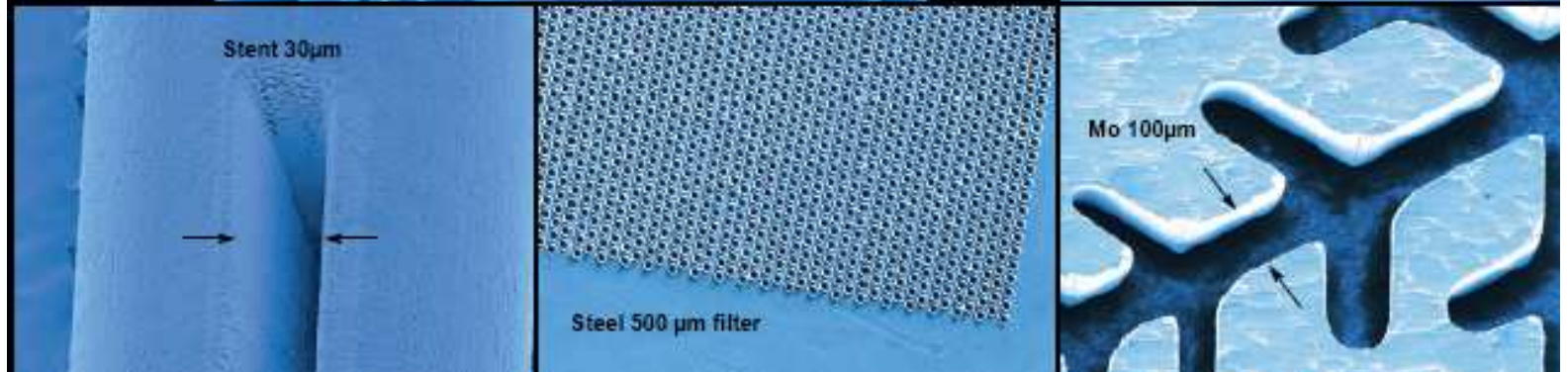
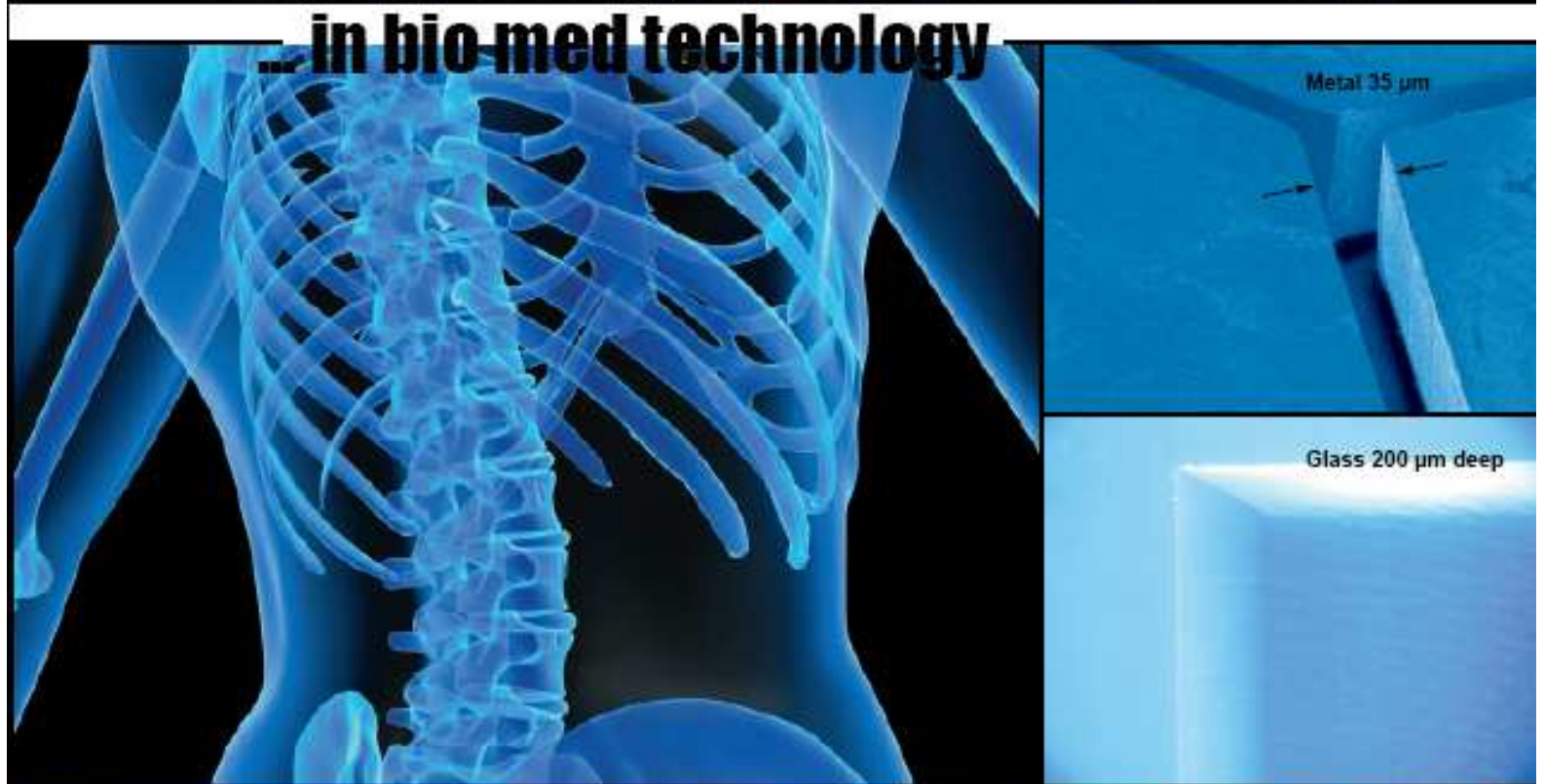




tough materials,
just in time
from CAD,

~10nm
depth
control,
~μm
lateral
resolution,
2.5D
structures

stents,
filters,
lab-on-
the-chip,
micro-
implants,
surgical
tools,
implant
surface
structures

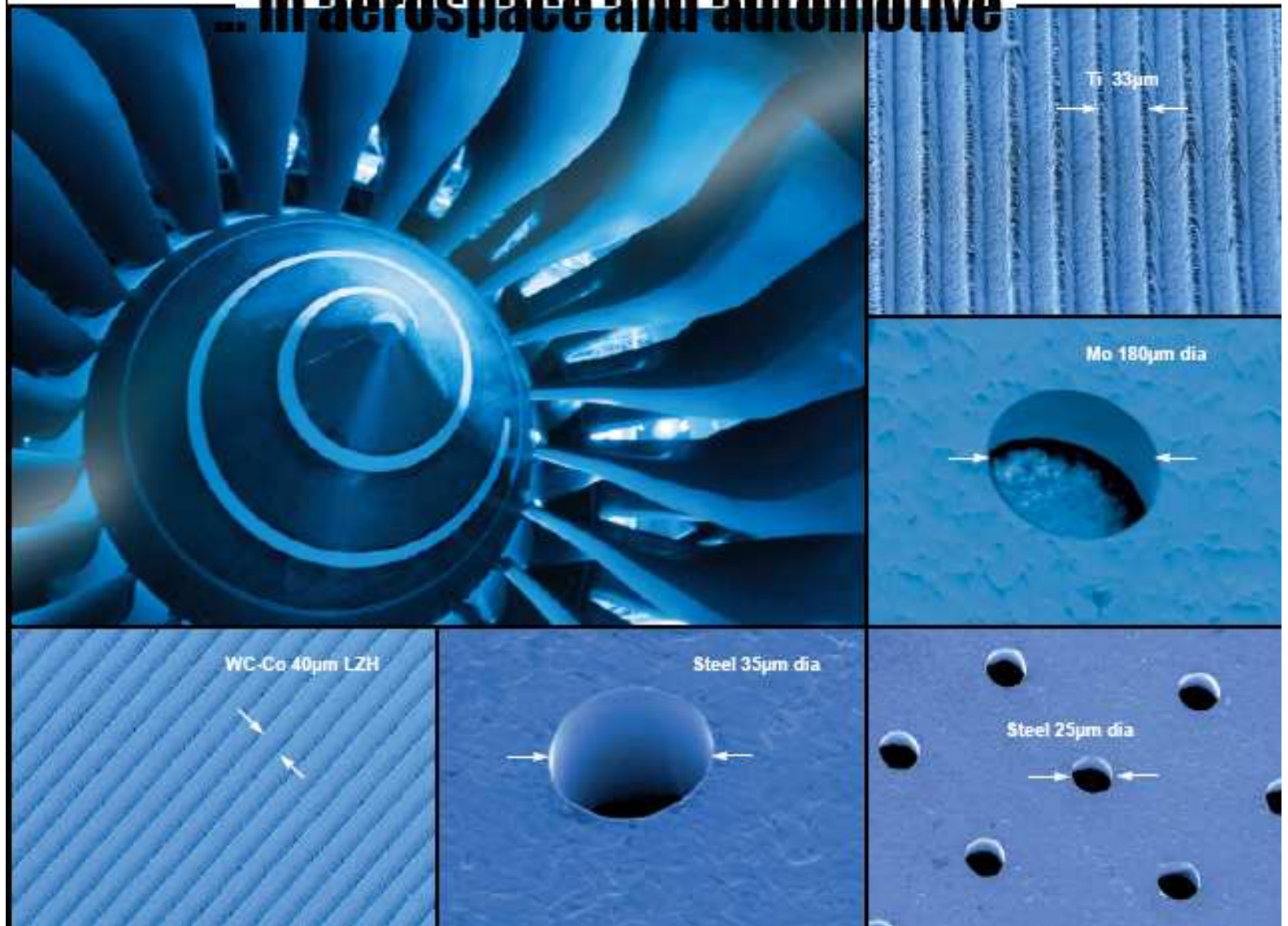


industrial ps laser micromachining

... in aerospace and automotive

... in aerospace and automotive

holes,
injection
nozzles,
grooves for
friction
reduction,
machining
tough
brittle
materials



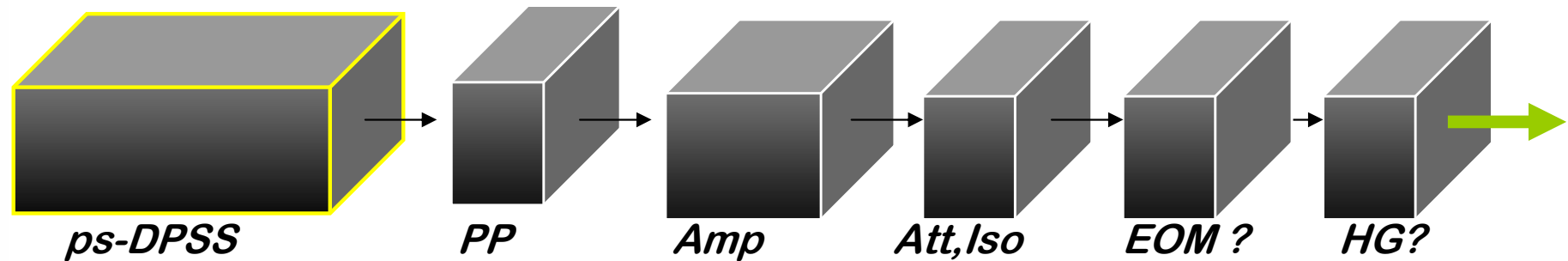
Company status

- **Ownership:** founded 2000, since Aug. 2008 part of Aton group (~3 bil \$)
- **Personnel:** ~60 +
- **Facility:** ~3000 m²; ~400 m² clean room; Application Lab, Job shop
- **Patents:** 8 Patent-Families, nat./ internat. (high RR EOM; 888nm pumping)
- **ISO 9001:** 2007



- **Product:** industrial ps-laser RAPID series
industrial ns-laser BLASE series
- **Net work:** global net of sales and service reps
- **Experience:** ~ 300 ps-lasers built
~ 7 mio h of operation
~ 700 samples processed

Products:
RAPID series of industrial ps-lasers



Mode-locked seed laser: 50 MHz pulses, $\sim 0.1 \mu\text{J}$

Pulse Picker: Picks 1 pulse (or more in burst mode)
out of e.g. 100 pulses at 500 kHz

Transient amplifier: amplifies pulse energy up to $\sim 200 \mu\text{J}$

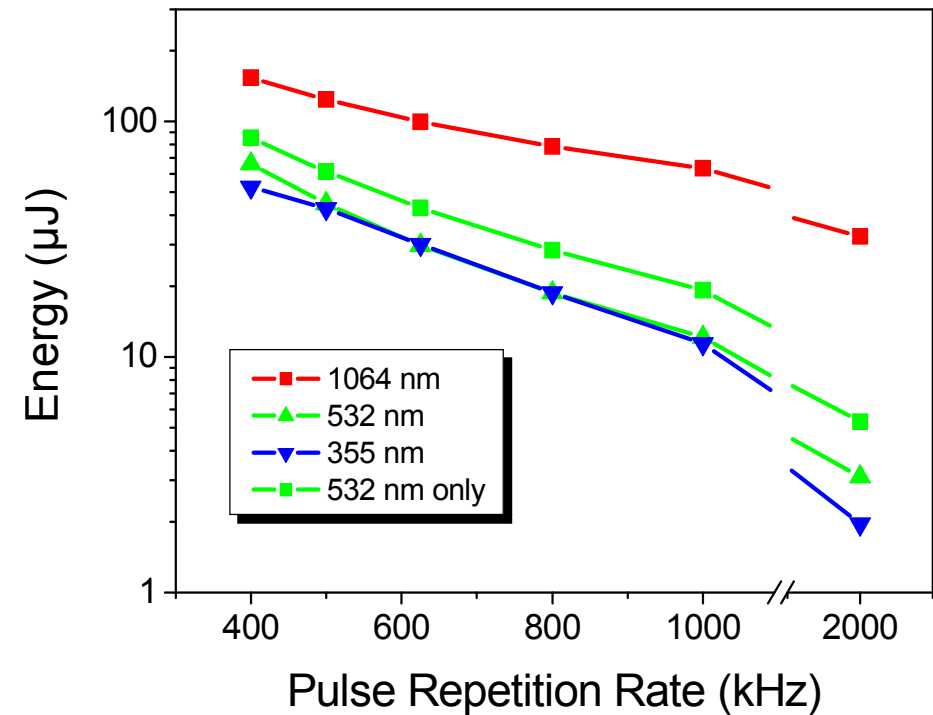
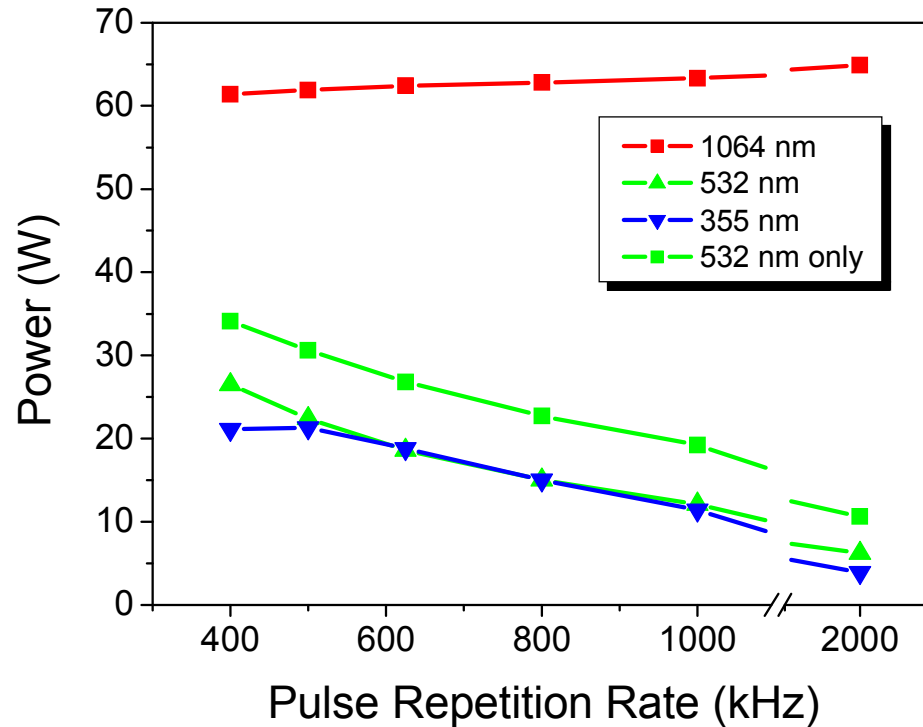
Attenuator, Isolator

Option: External EOM Pulse Picker

Option: Harmonic Generator: converts IR pulses to green and UV
532nm, 355nm (266nm); with 0-air generator

HYPER RAPID 50

typical data



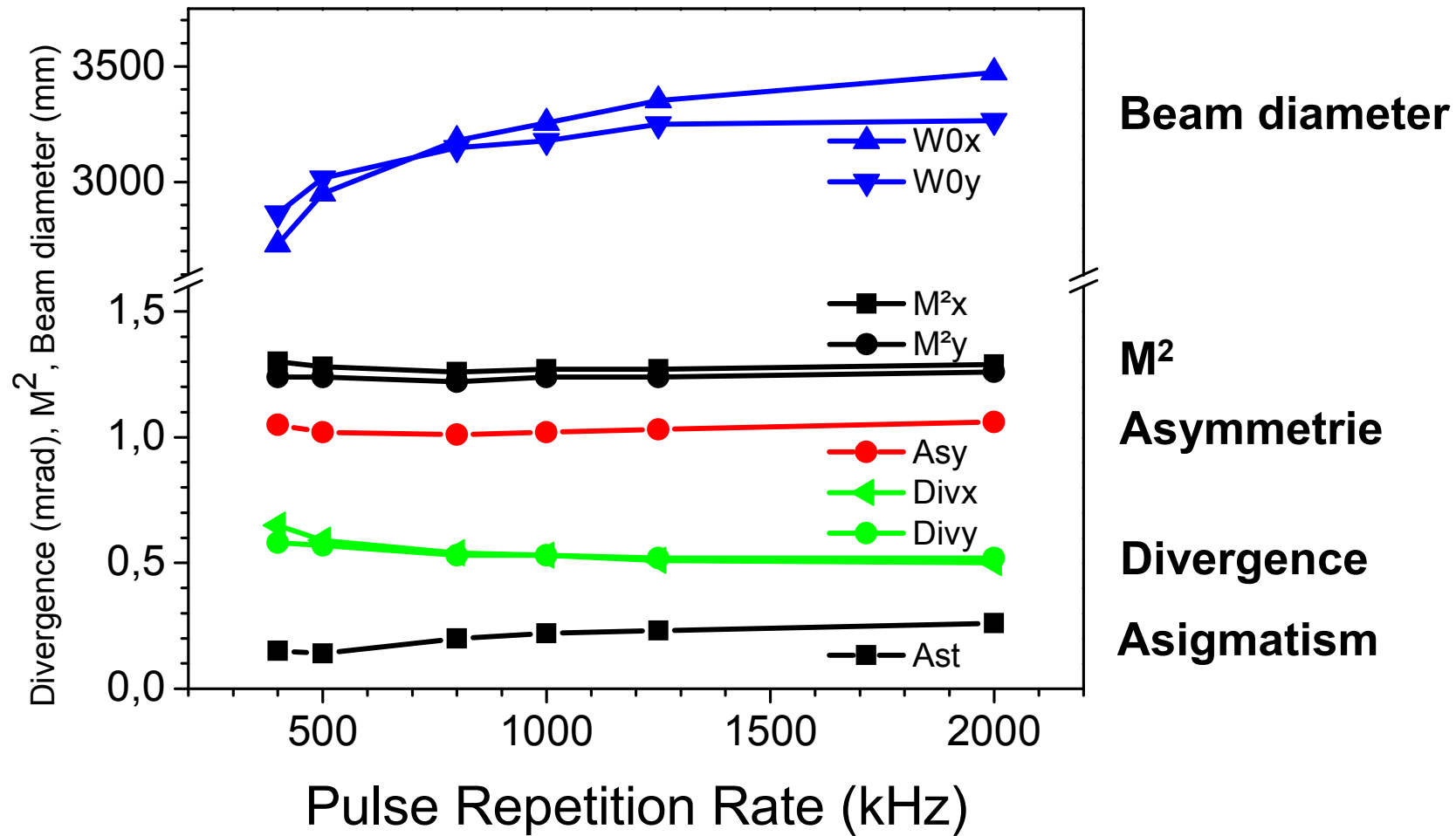
PRF: 400 – 1000 kHz (opt. 2MHz), E: 125 – 50 µJ; $M^2 < 1.5$

1064 nm: 50 W @ 1 MHz

532 nm: 25 W @ 400 kHz

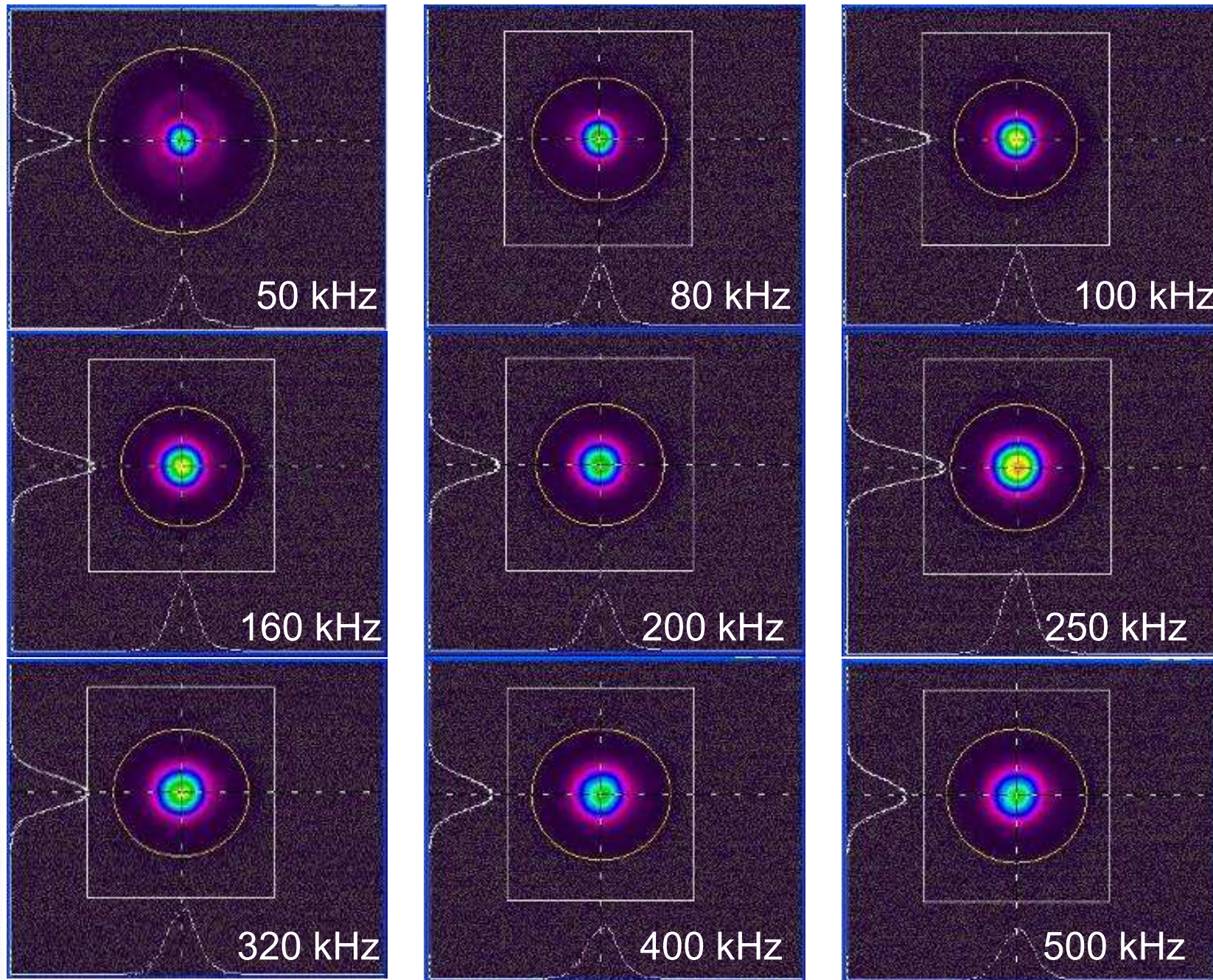
355 nm: 16 W @ 400 kHz

HYPER RAPID 50

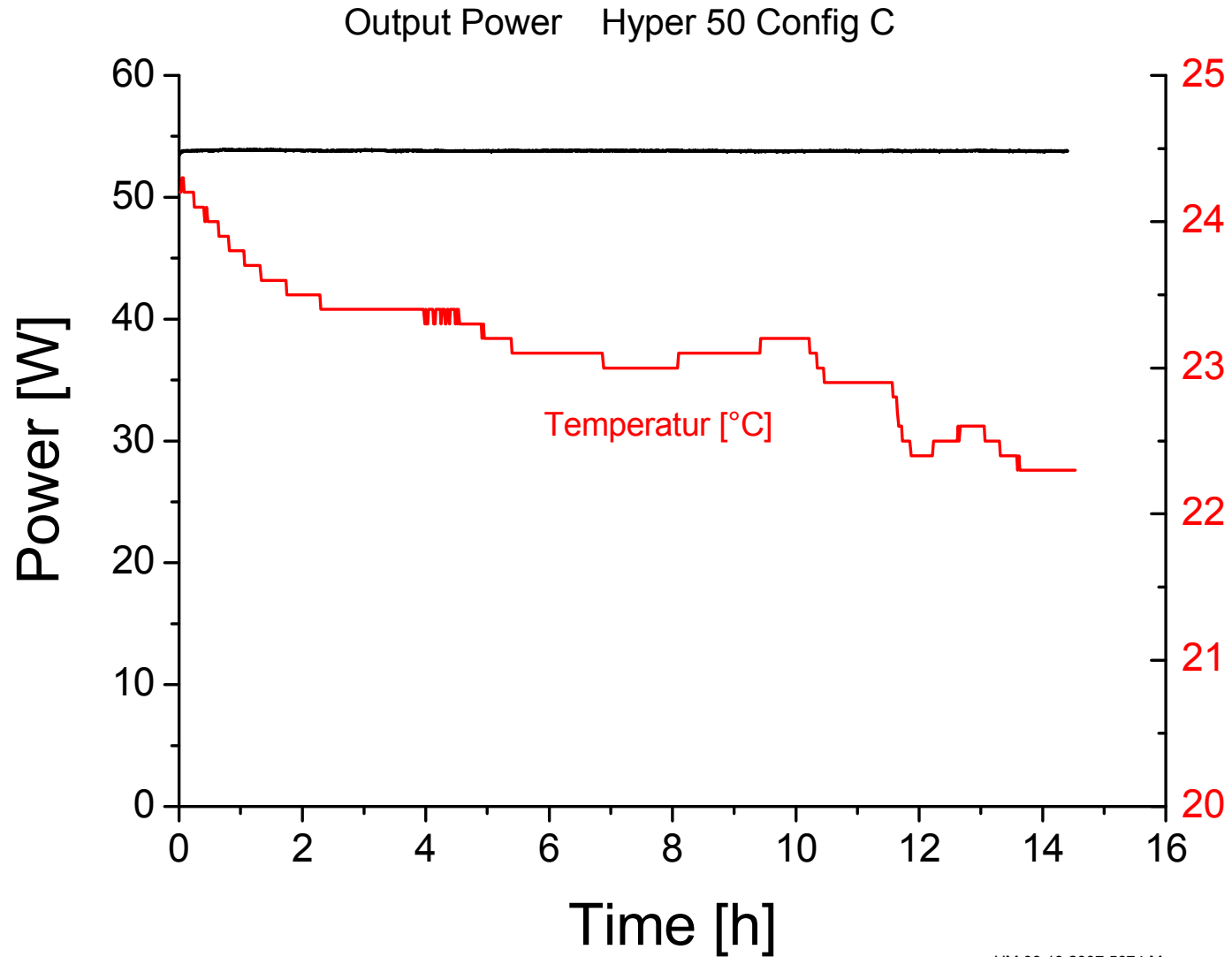


⇒ **almost ideal beam with low variance vs. PRF**

Mode profile vs PRF



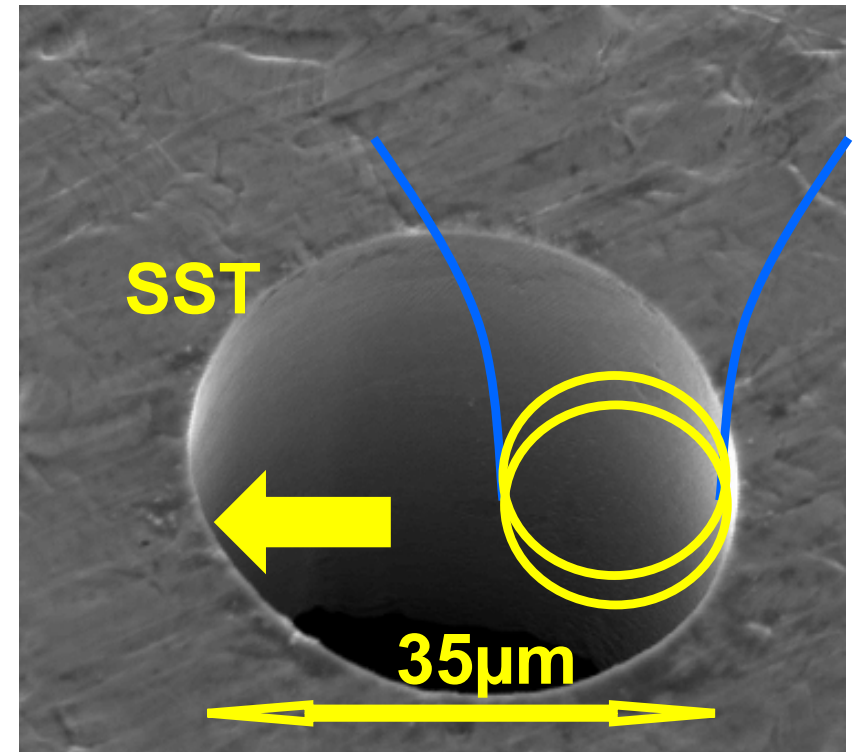
HYPER RAPID 50 : P vs T



HM 09.10.2007 5074 Messungen.opj

REMEMBER:

- 1. high resolution**
- 2. high quality**
- 3. any material, same universal laser**
- 4. high removal rate:
up to 60mm³/min with 50W,
with high RR up to 2MHz ,
with burst-mode**
- 5. low TCO
in 24-7-use ~0.2€/min**



Resolution

z: ~10-100nm / pulse

x, y : <µm

