Amplitude SYSTEMES

Industrial micromachining with ultrafast laser : comparison ps-

ALPhA NOV
Centre Technologique Optique et Lasers

John Lopez, Rainer Kling

Bern University of Applied Sciences
Institute for Applied Laser, Photonics and Surface Technologies ALPS

Beat Neuenschwander, Beat Jaggi

- Amplitude Systemes
- Application in the industry
- Ultrafast laser technology
  - Direct diode pumping
  - Fiber and crystals based lasers
  - Laser architecture
  - State of the art
- Picosecond versus femtosecond abblation efficiency with high average power
- Picosecond versus femtosecond abblation efficiency for single pulse
- Processing quality comparison between picosecond and femtosecond

Amplitude Systemes



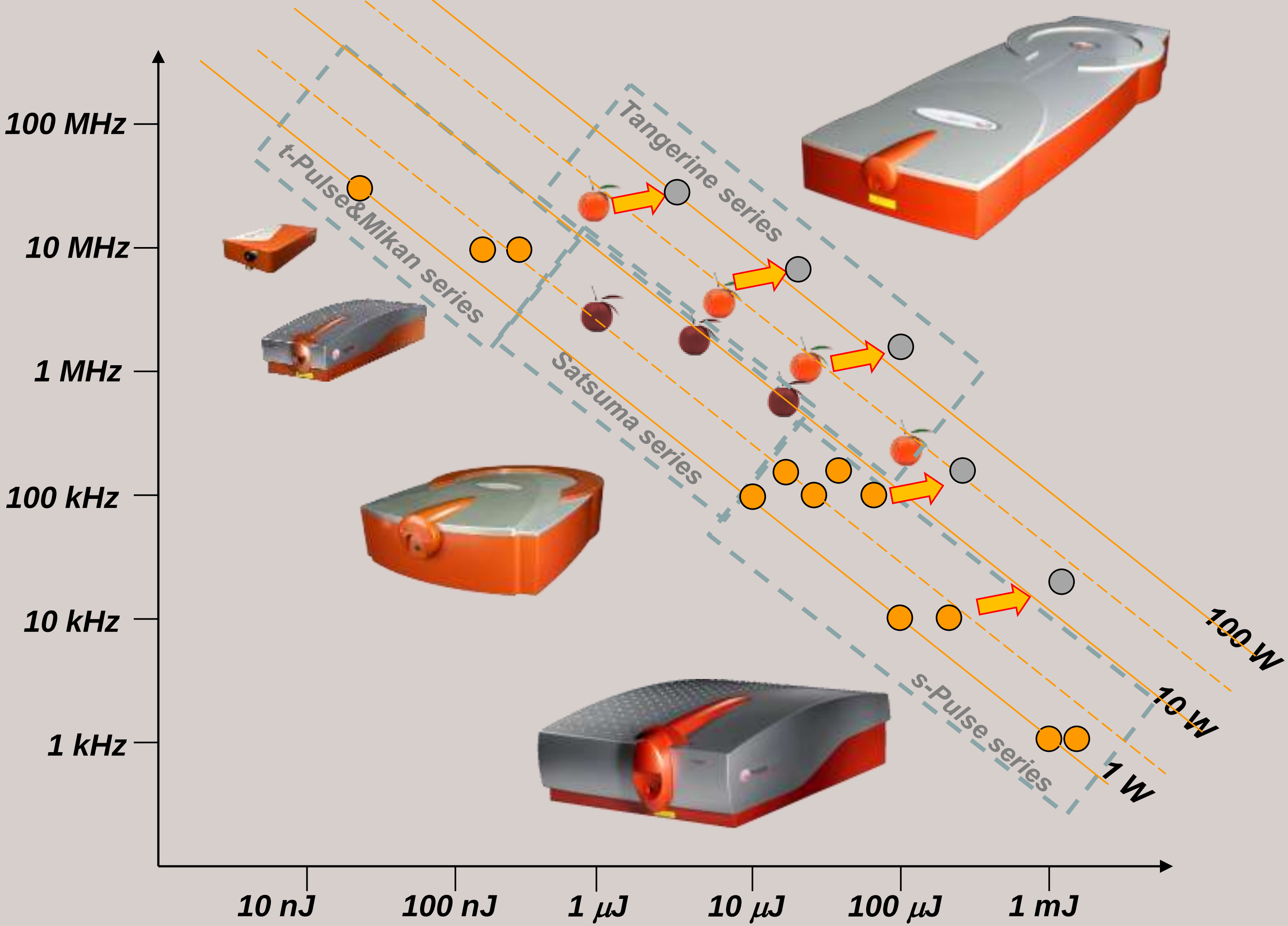

Amplitude SYSTEMES

Company

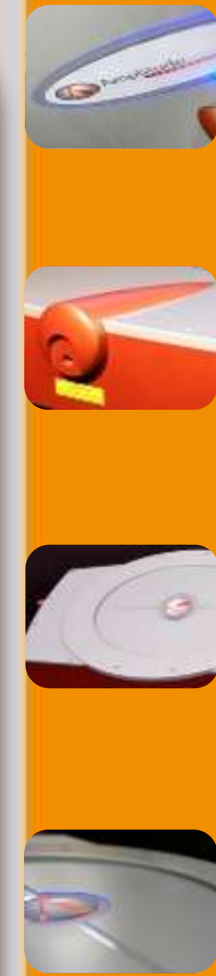
Amplitude Asia – Taipei & Shanghai

- Created in 2000
- 120 employees in ultrafast lasers
- More than 500 lasers in the field
- Pioneer in diode pumped ultrafast lasers
- Strong R&D policy

The largest product range

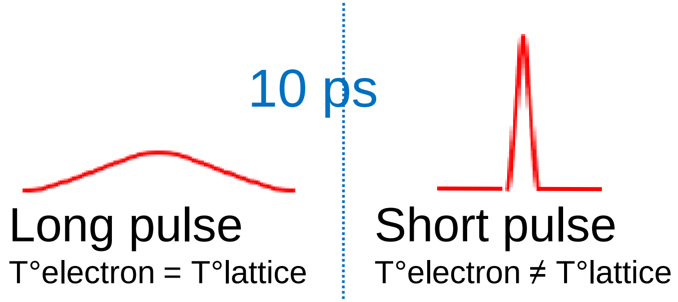


Application in the industry



Pulse duration and mechanism

Theoretical value for heat diffusion time

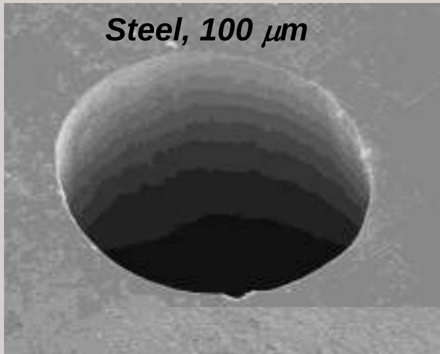


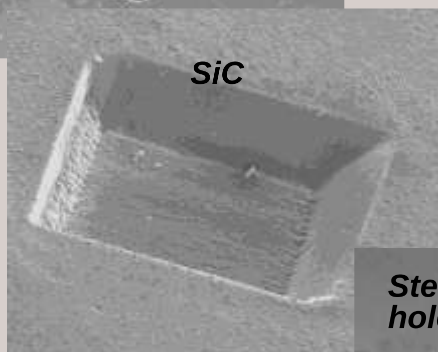
1 to 50 ps

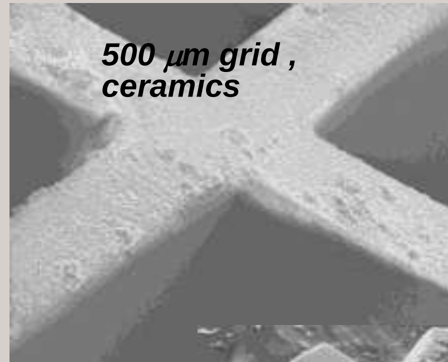
	Long pulse (> 50 ps)	Short pulse (<1 ps)
Ablation rate	☺	☹
Side effects	☹	☺
HAZ	☹	☺

Competition between the two mechanisms

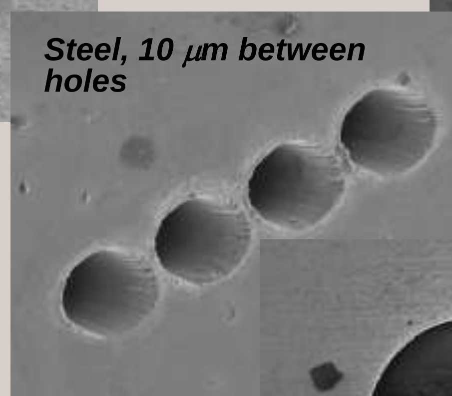
Micromachining

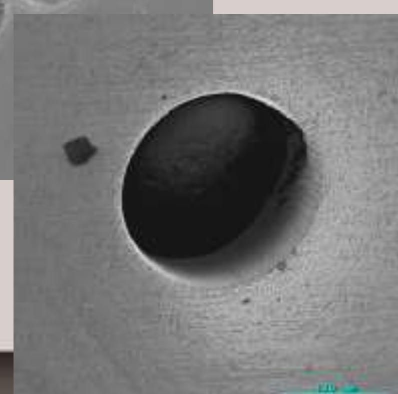

Steel, 100 μm

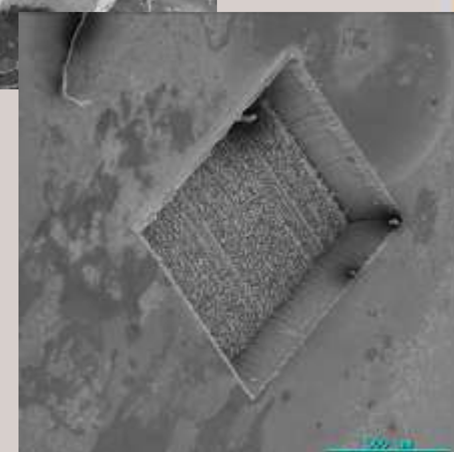

SiC


500 μm grid , ceramics

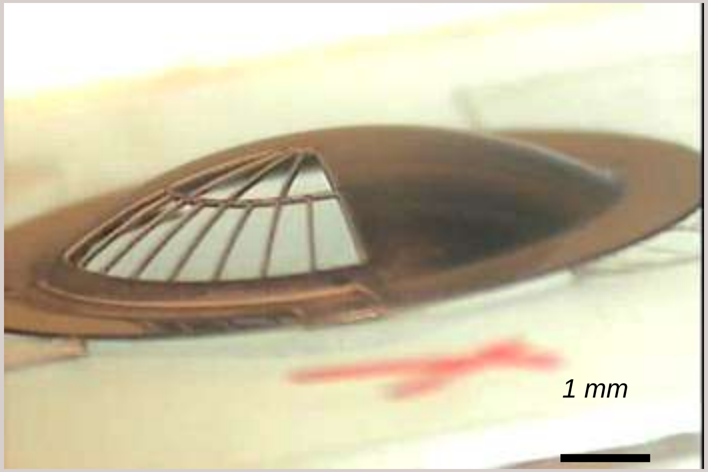

Steel, diameter 1mm


Steel, 10 μm between holes

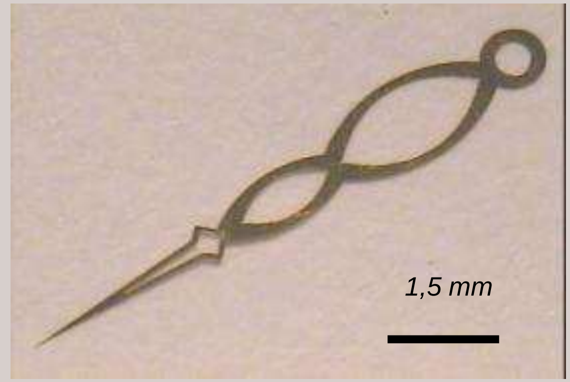




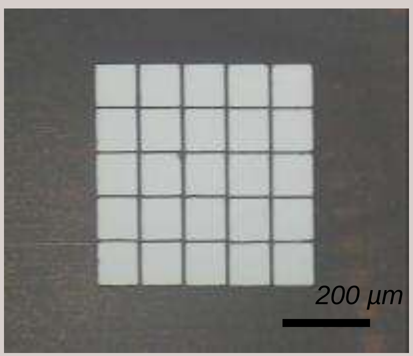
Micromachining



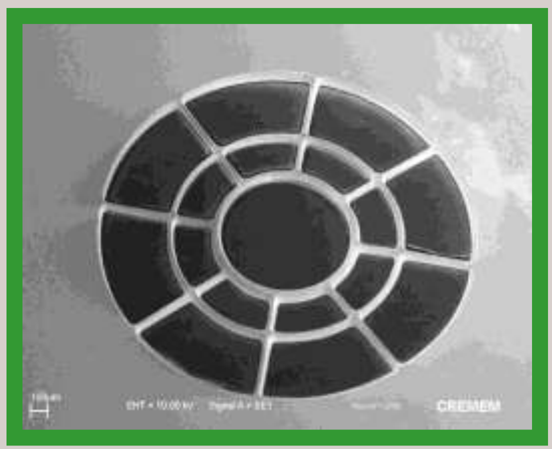
Metal - thickness.50µm
Bars width 90µm



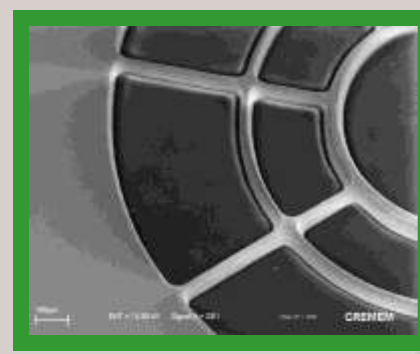
Gold - thickness.25µm



Platin - thickness.10µm
Bars width 10µm



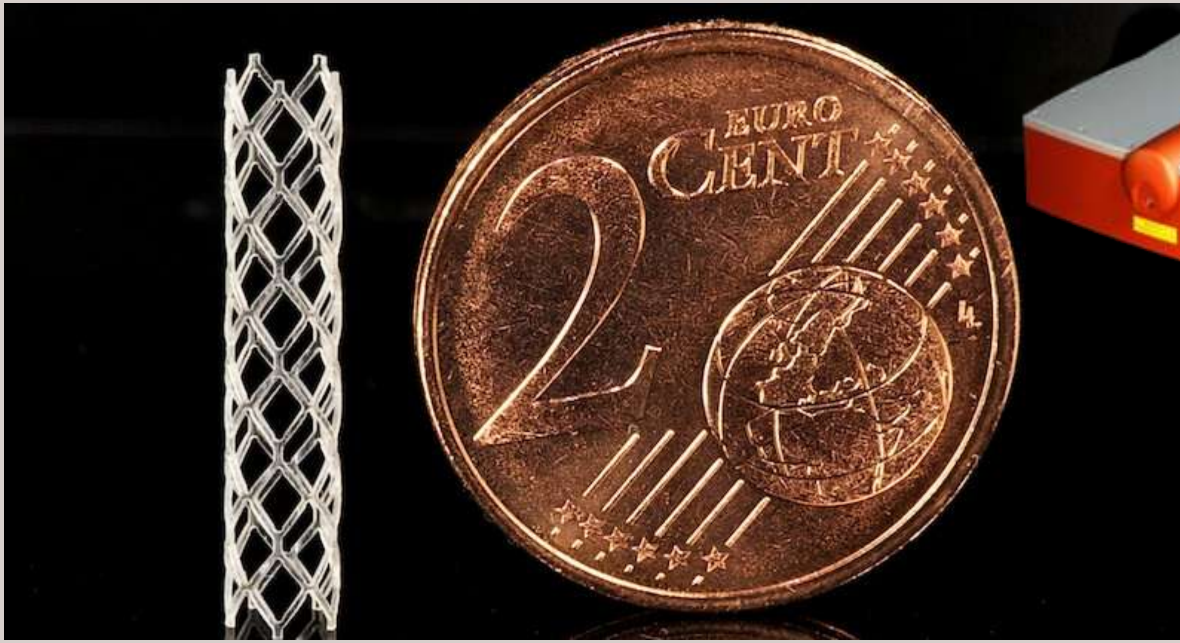
Tungsten - thickness. 100µm
Bars : 100µm

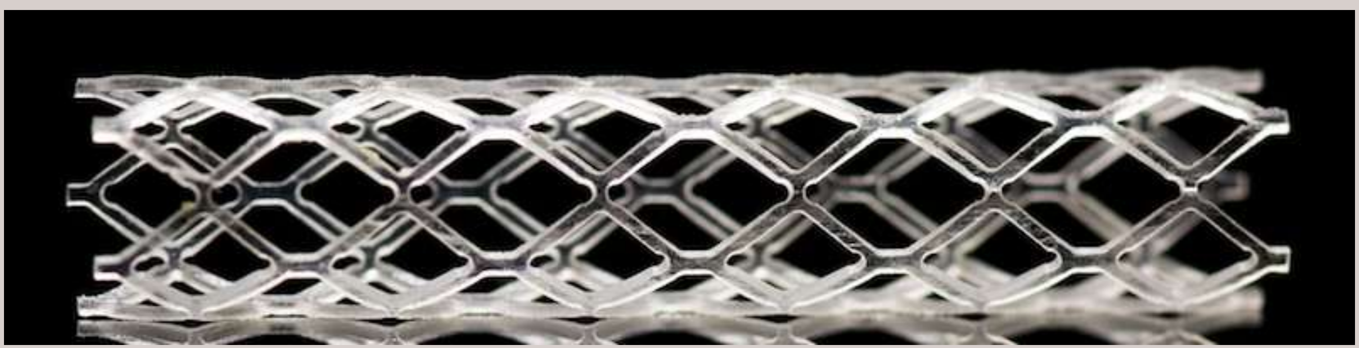


Amplitude SYSTEMES

Medical device manufacturing

Metal or bio-polymer machining

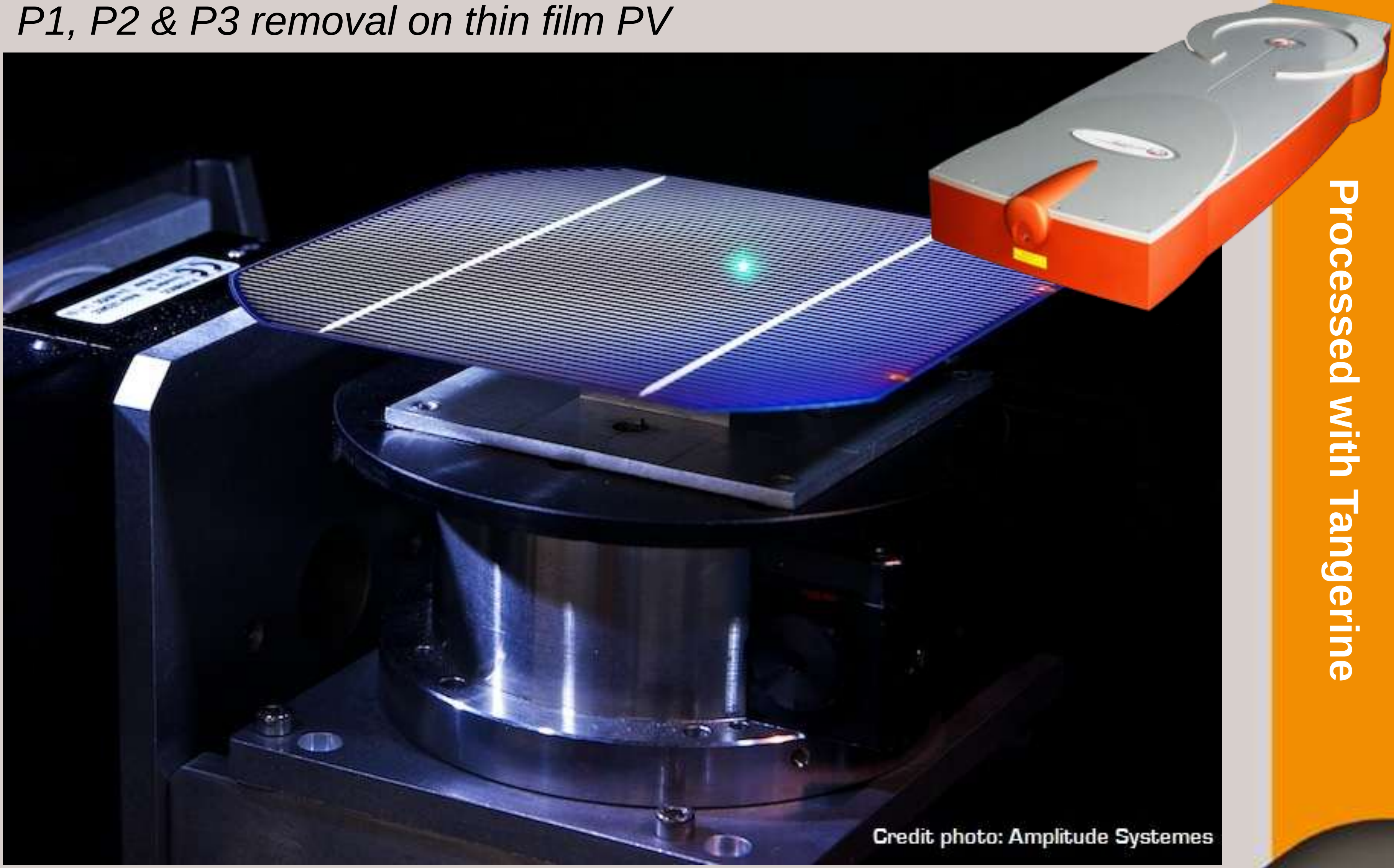




Processed with Tangerine

Photovoltaics

P1, P2 & P3 removal on thin film PV

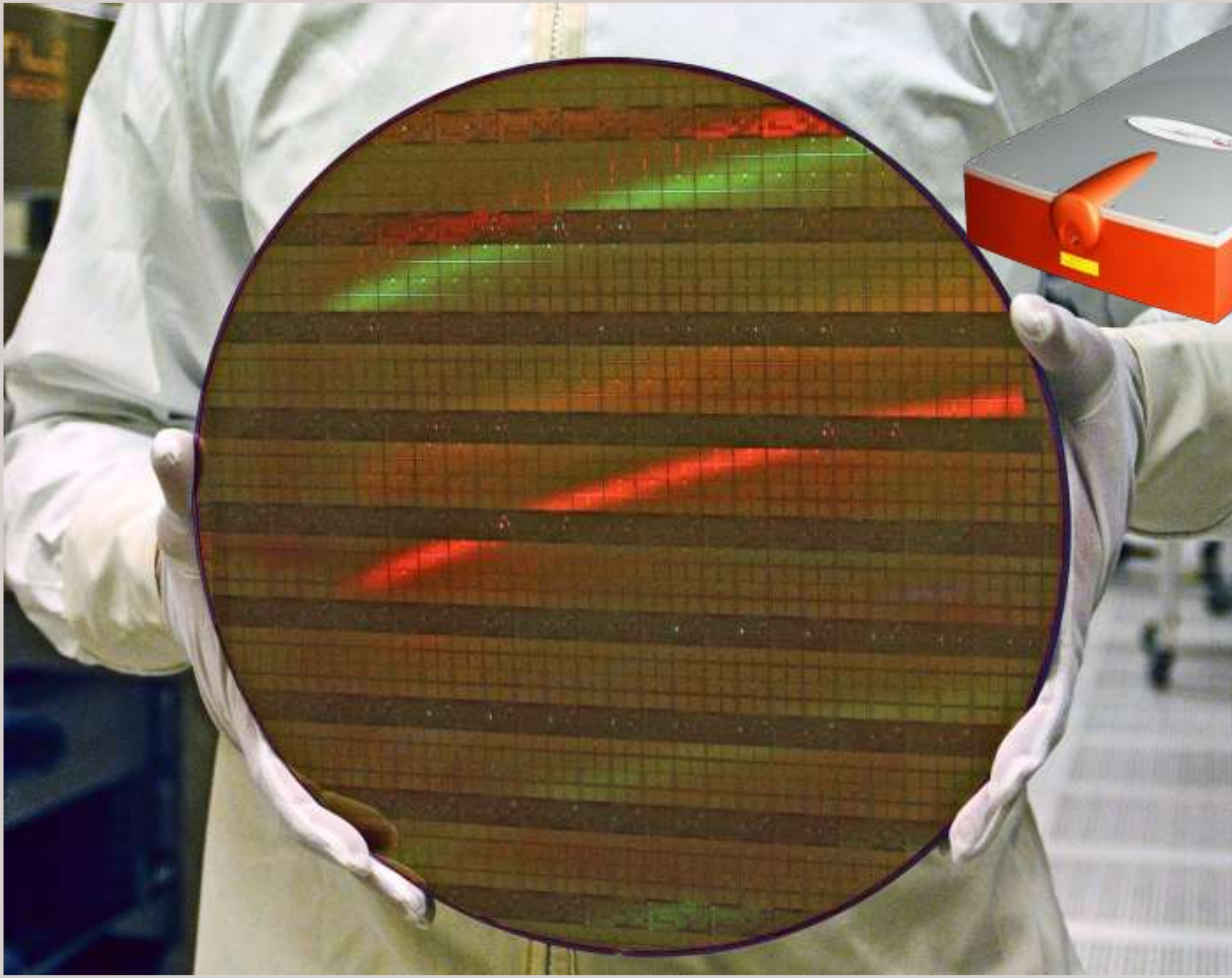


Processed with Tangerine

Amplitude SYSTEMES

Thin film removal

Wafer thin film removal



Processed with Tangerine

Transparent material cutting

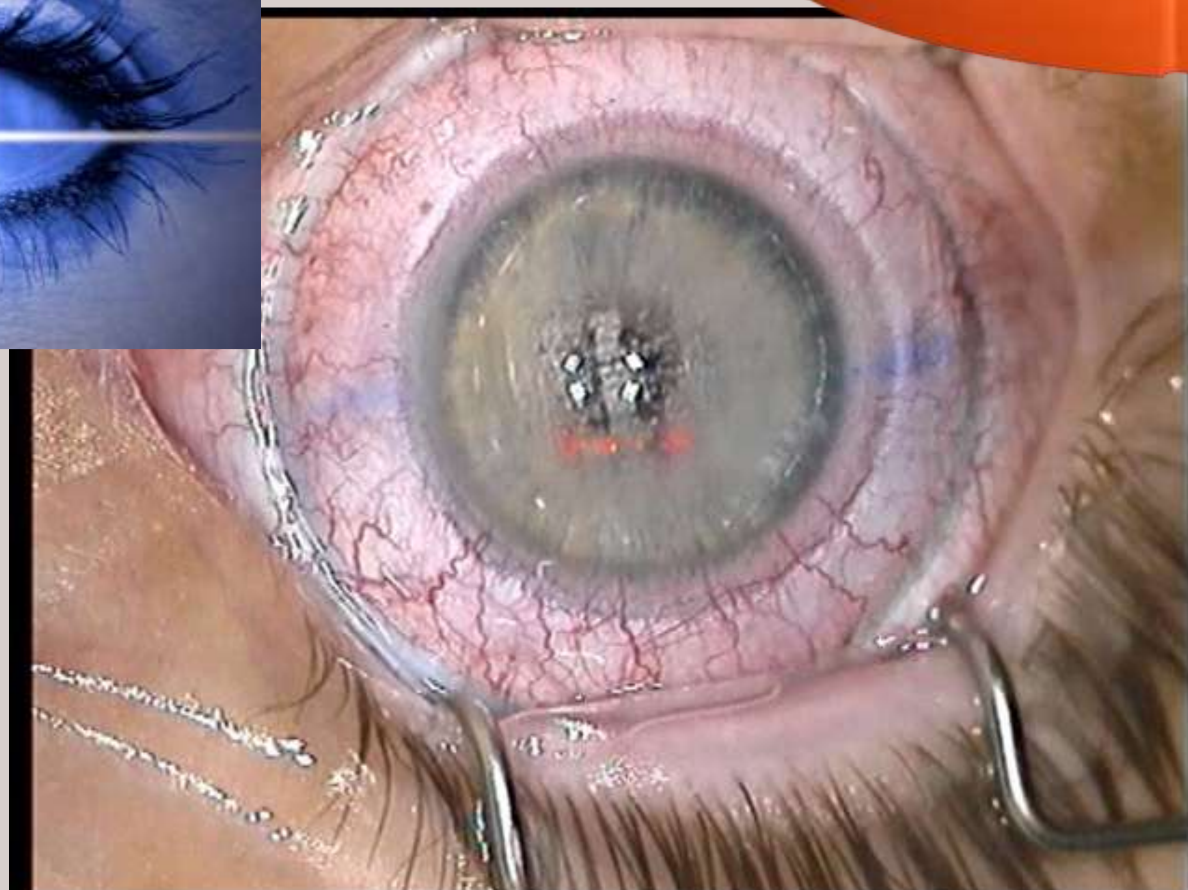
Saphire cutting

Processed with Tangerine

Amplitude SYSTEMES

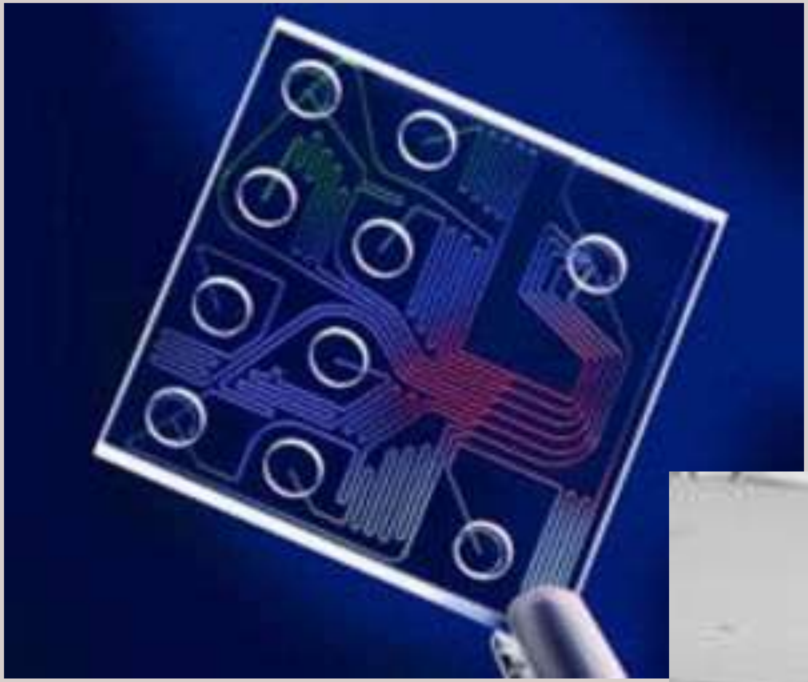
Eye surgery

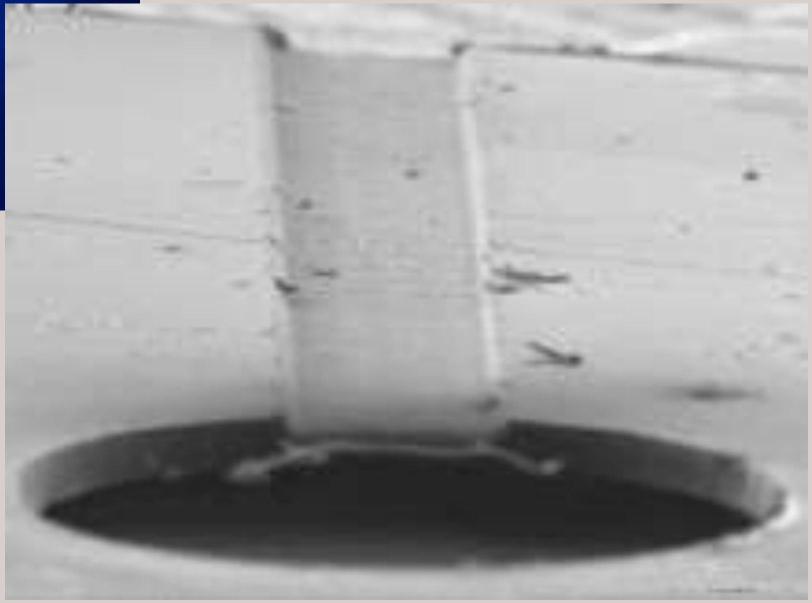
Leader in ultrafast eye surgery



Processed with Satsuma

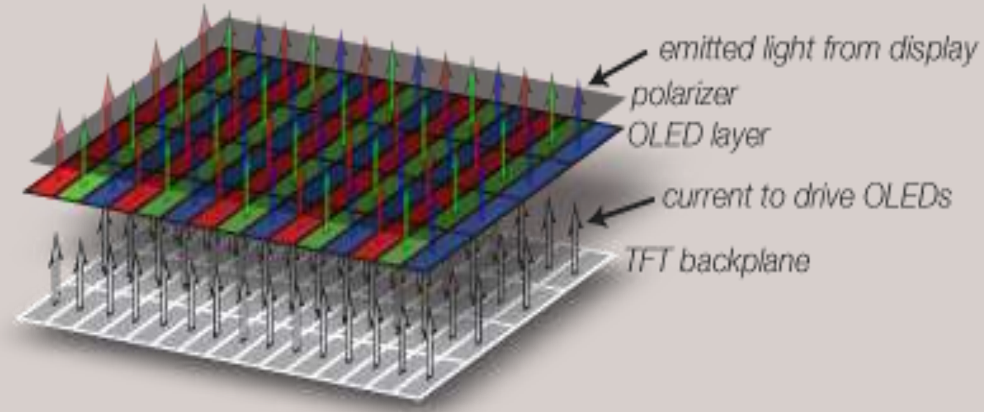
Lab-On-Chip

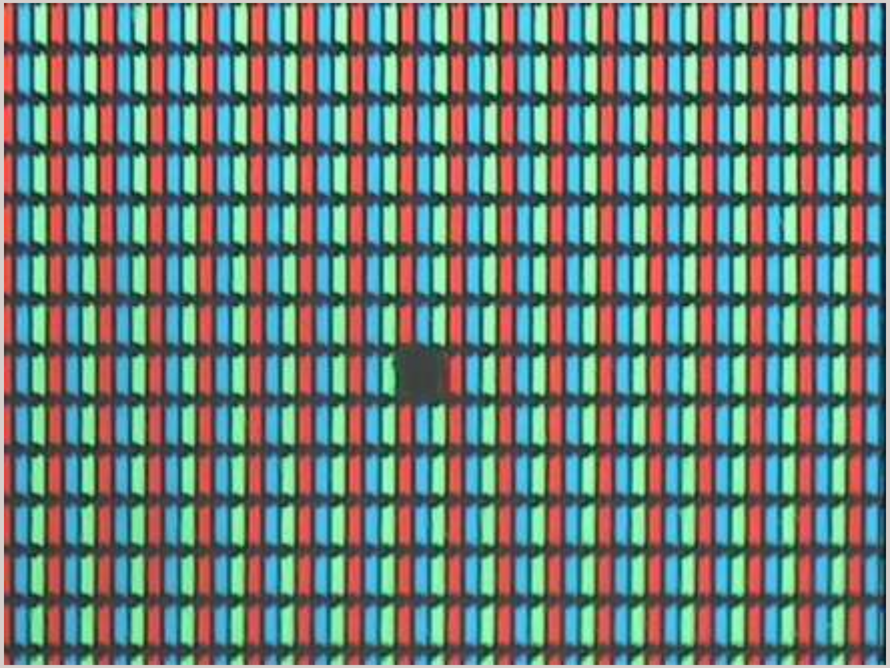




Processed with Satsuma

Display industry

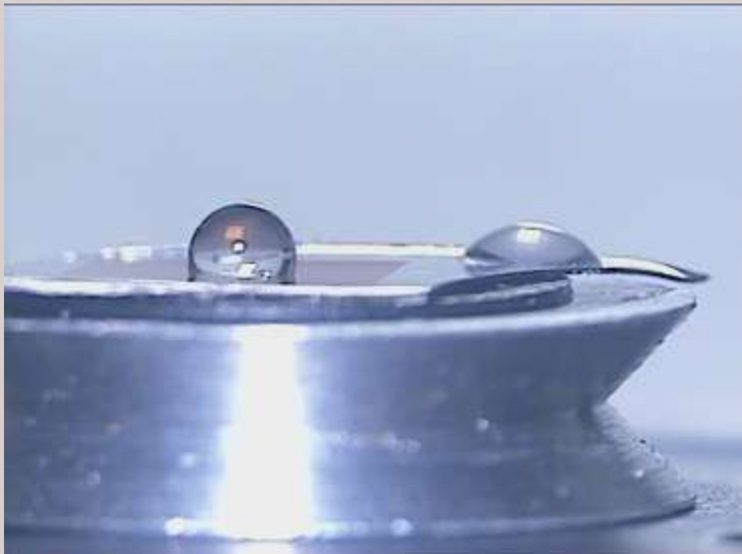


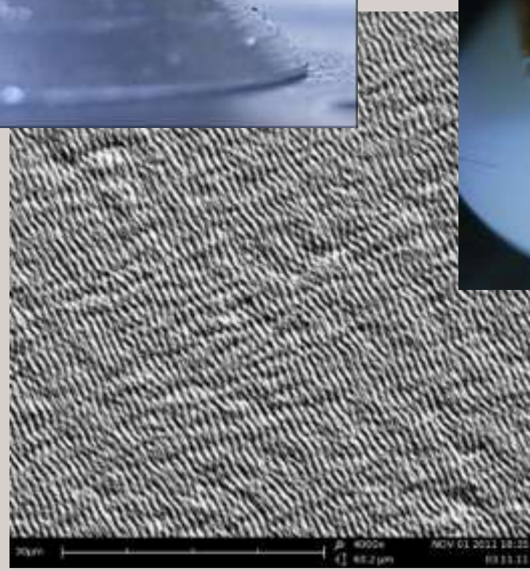


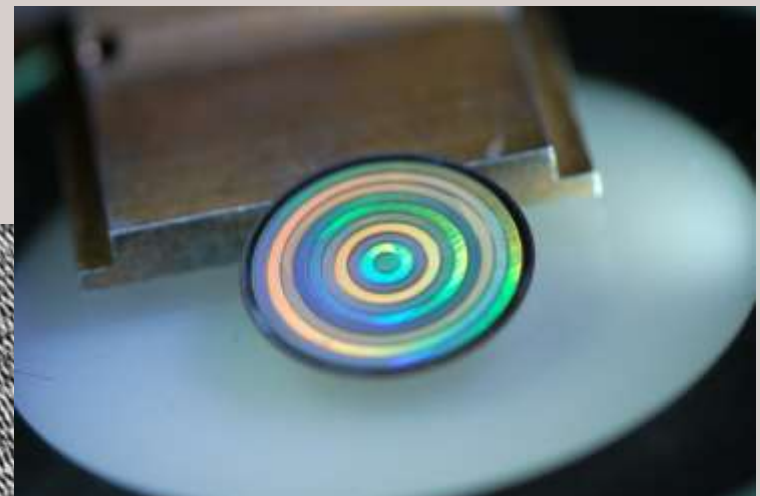
- *LCD screen*

- Organic layers (OLED)

Surface structuring



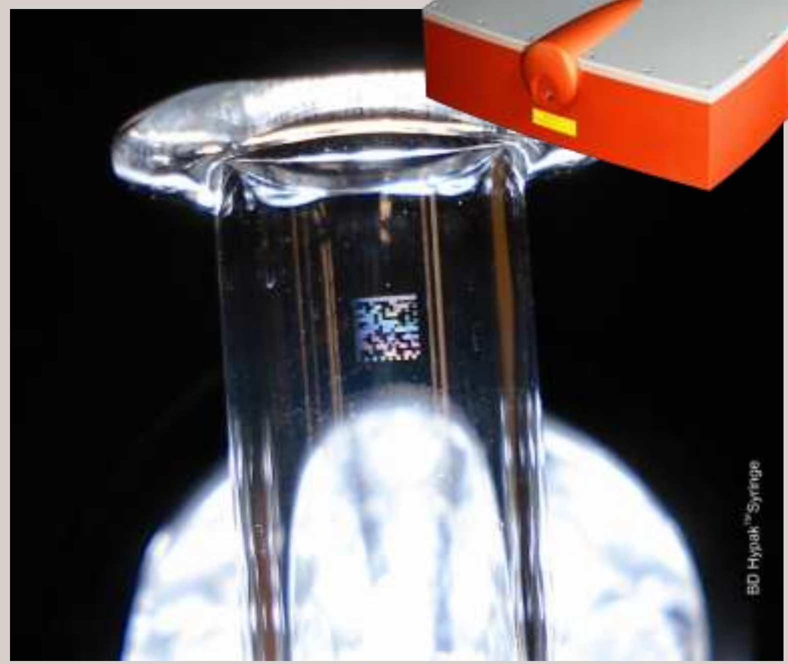




Courtesy Alphanov

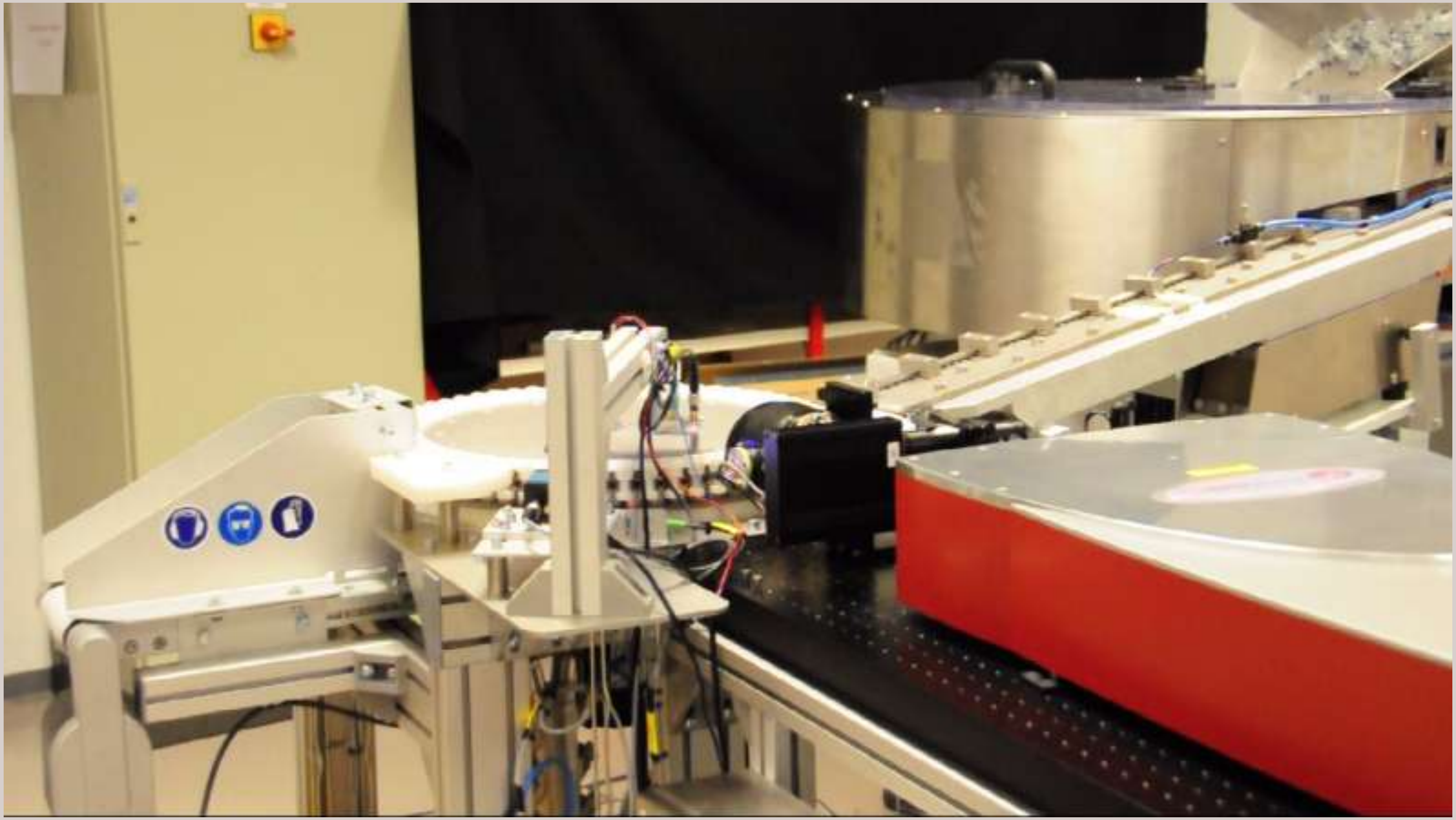
Processed with s-Pulse HP

Internal marking



Processed with Tangerine

Internal marking



Nanoparticles generation

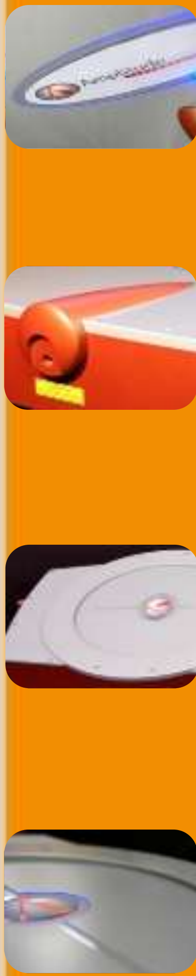
Courtesy Alphanov

Processed with s-Pulse HP²

Gold nanoparticles

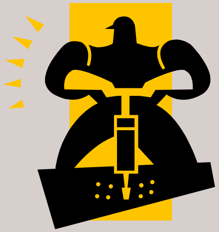
Amplitude SYSTEMES

Ultrafast laser technology

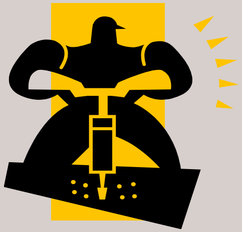


Direct diode pumping

- More compact laser
- More stable laser
- Higher quantum efficiency: low thermal management
- High average power capability



Dedicated for the industry

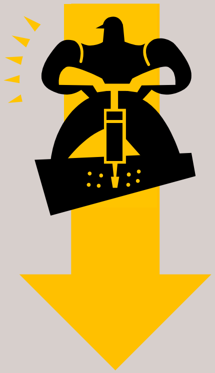


Solid state	**Fiber laser**
Regenerative amplifier	In-line amplification
High energy output capability (up to 2mJ)	High average power capability (up to 100W)
Thermal management: average power up to 30W in femtosecond	Non-linear effects management : energy up to 100µJ with rod type amplifier

Amplitude SYSTEMES

Solid state

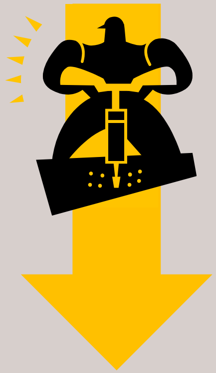
Ideal for high energy application



- Large surface treatment
- In depth drilling or cutting
- Multiple beam

Fiber laser

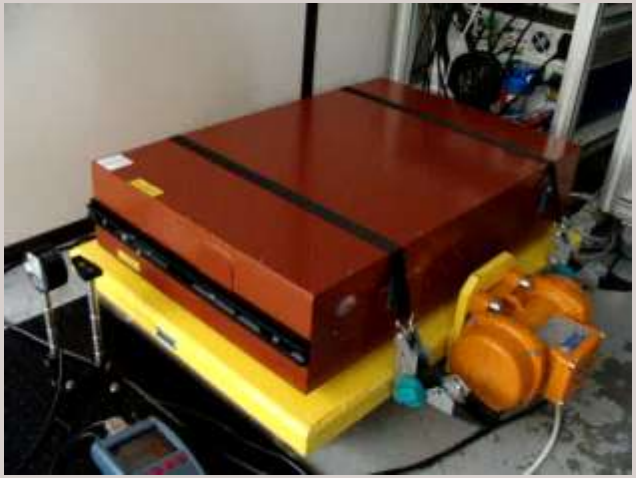
Ideal for high repetition rate application



- Thin film removal
- Heat accumulation regime
- Engraving

Laser architecture

- Stretcher & compressor are in addition compared to picoseconds laser
- Stretcher & compressor can be extremely compact and stable nowadays



24 HOURS 3g VIBRATION TESTING ON A 1mJ LASER (s-Pulse HP)

Production environment

- 20000 sq ft clean room production space

- More than 700 check points during production

Large production cabability

ISO 9001 certified

- ISO 13485 certified

Industrial Production



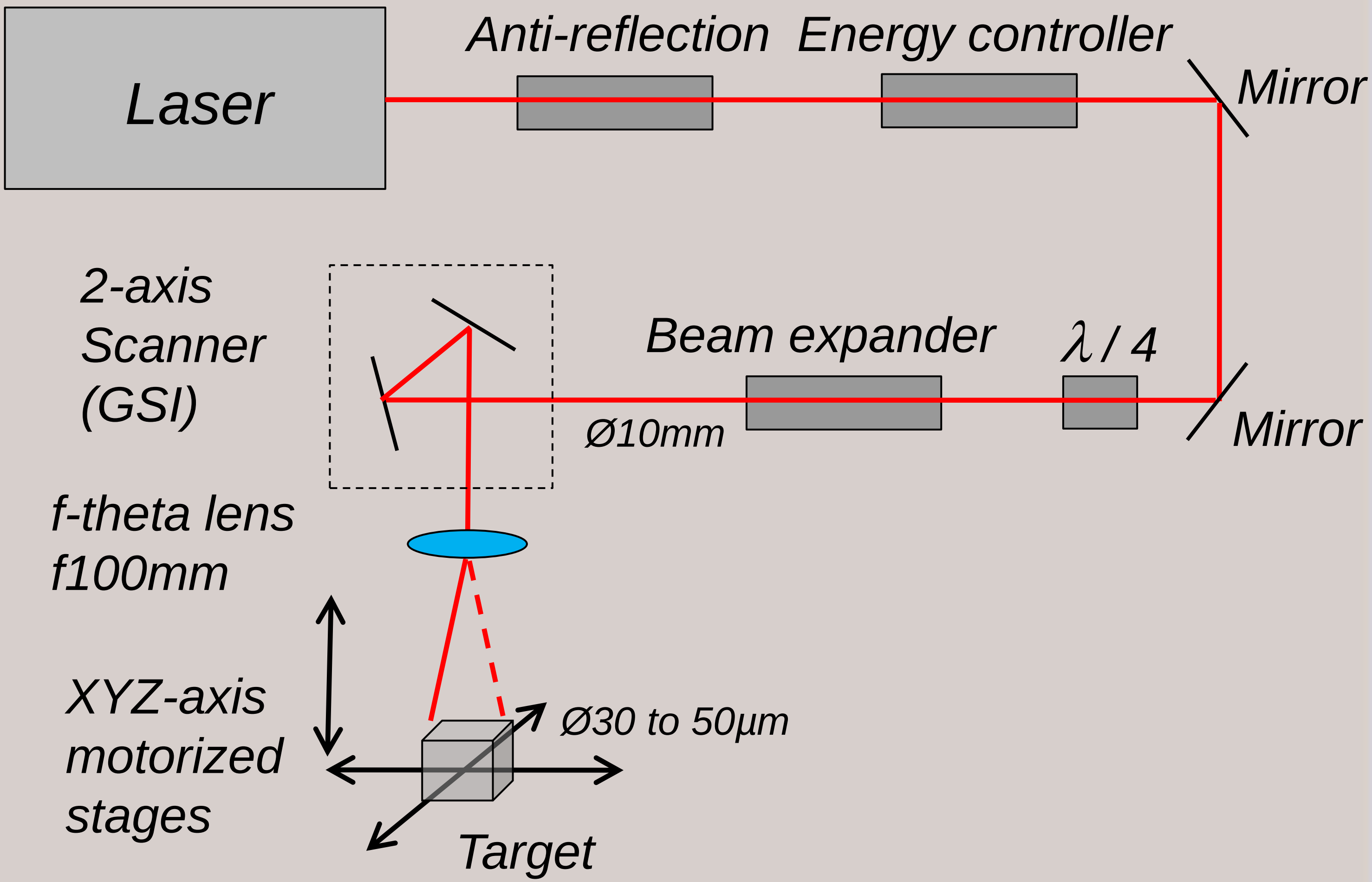
Femtosecond are now industrial in terms of production capability and reliability



Ps versus fs efficiency at high average power

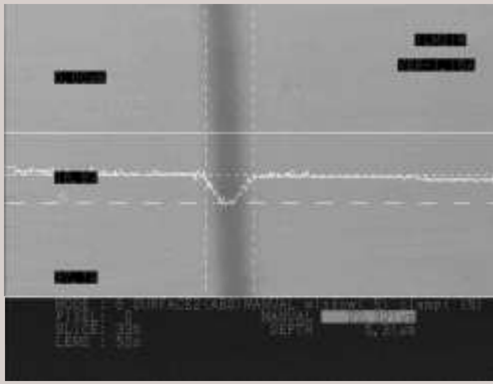
ALPhA NOV
Optics & Lasers Technology Center

Experimental setup

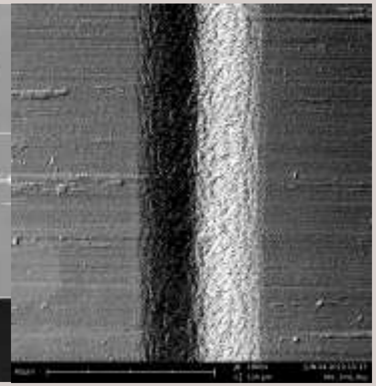


Experimental protocol

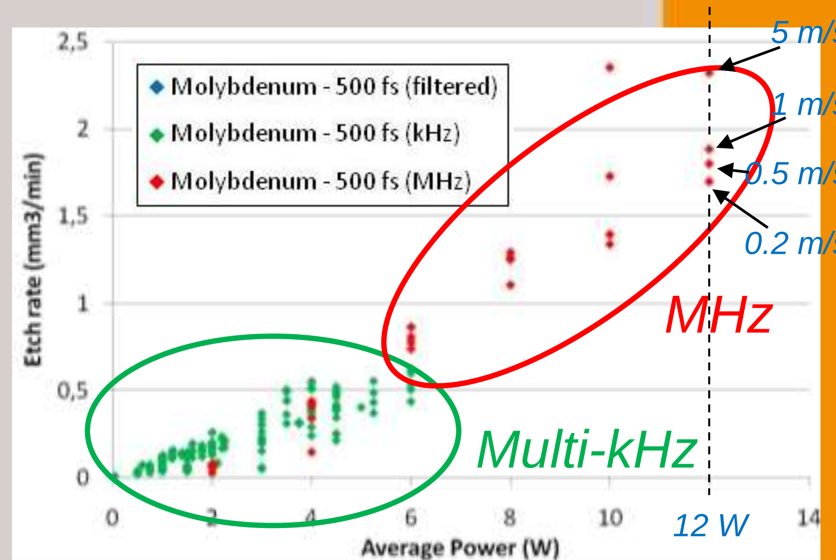
for etch rate investigations



Groove width and depth measurement

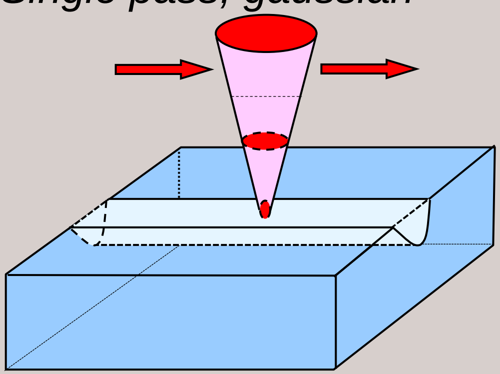


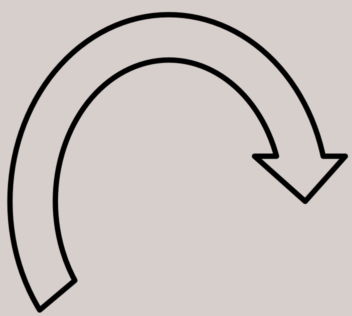
SEM analysis

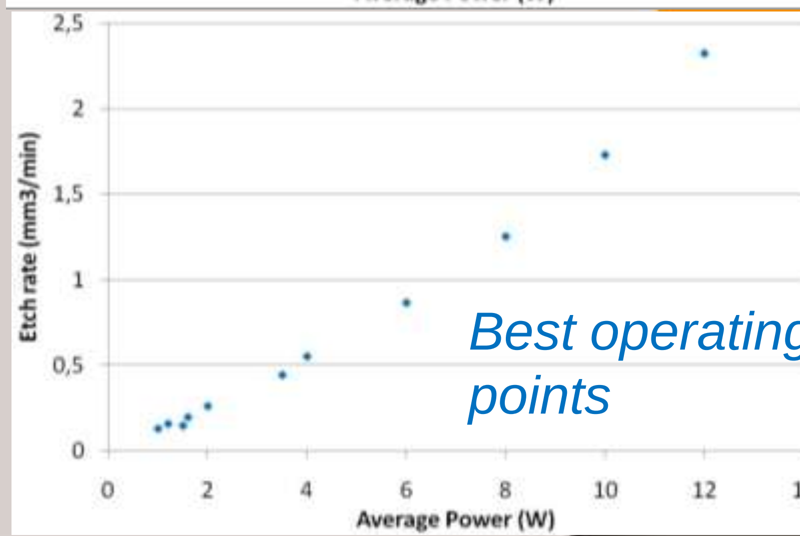


Laser exposure

Single pass, gaussian

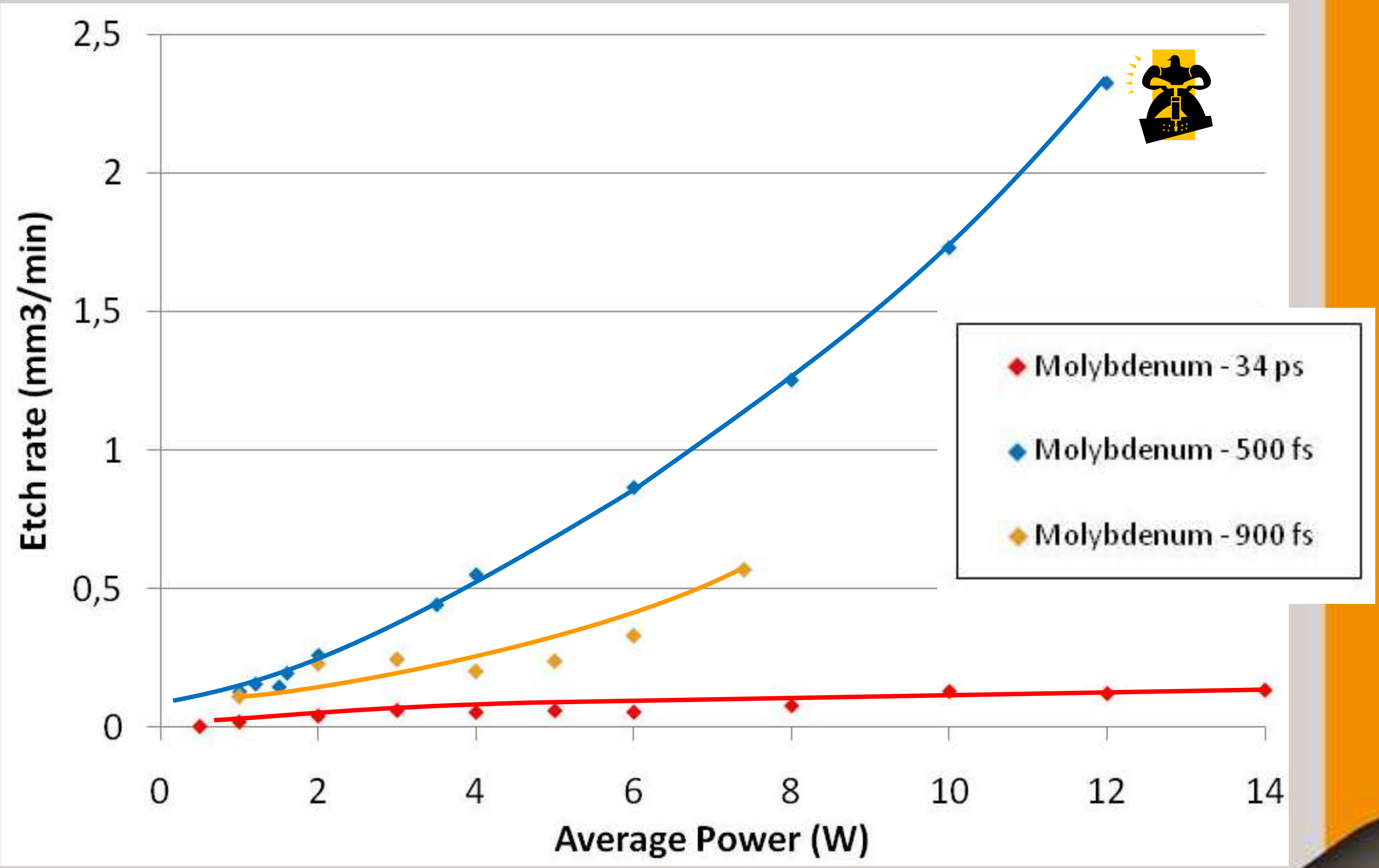






Repetition rate fixed. For each pulse energy value : Scan velocity ranges from 100µm/s to 5m/s

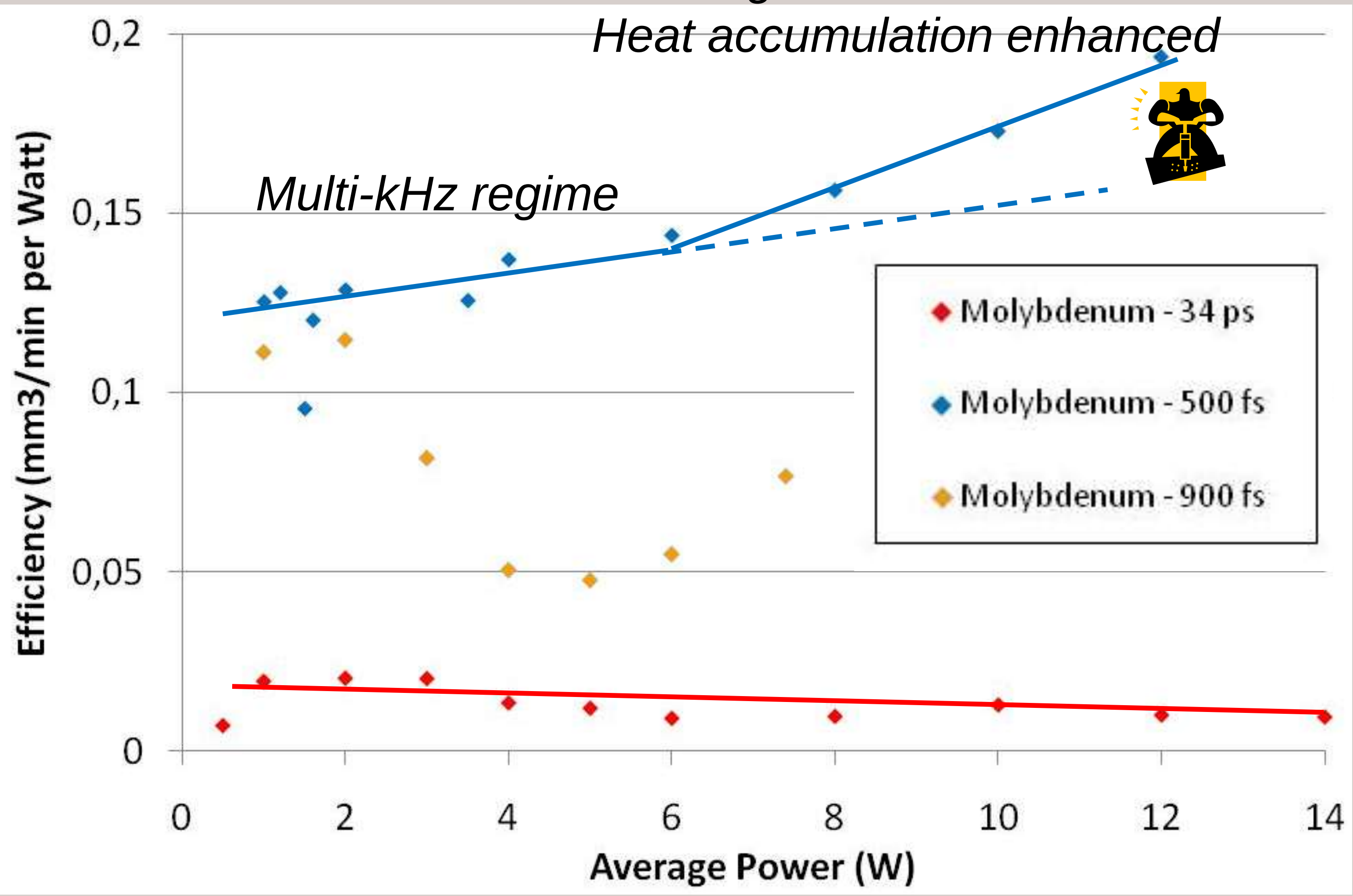
Etch rate vs Average power
On Molybdenum



Process efficiency (Power)

On Molybdenum

MHz regime
Heat accumulation enhanced



Processing efficiency comparison

On several materials

Best efficiency at 500fs

	Efficiency in Power mm³/min per Watt			
Pulse duration	500 fs		900 fs	34 ps
Rep. rate	1kHz to 2MHz	200kHz	200kHz	200kHz
Molybdenum	0.19	0.11	0.1	0.02
Silicon	0.38	0.17	0.19	0.04
Copper	0.26	0.14	0.21	0.07
Nickel	0.25	0.19	0.28	0.03
Stainless St.	0.19	0.13	0.2	-
Brass	0.45	0.24	0.26	0.08
Aluminum	0.6	0.35	-	0.05
Glass	0.28	-	-	-
PI	3.6	3.6	-	-
PC	1.5	0.87	1.1	-

x10 x4 x5 x6 x2 x3

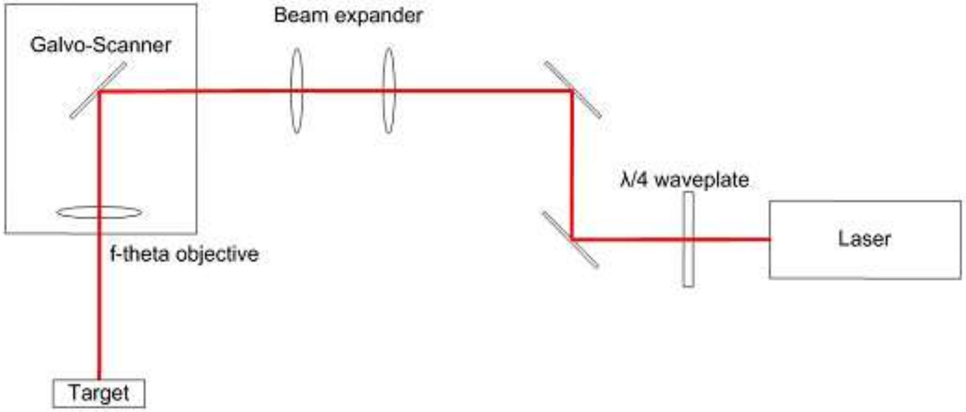
Ps versus fs efficiency without heat acumulation

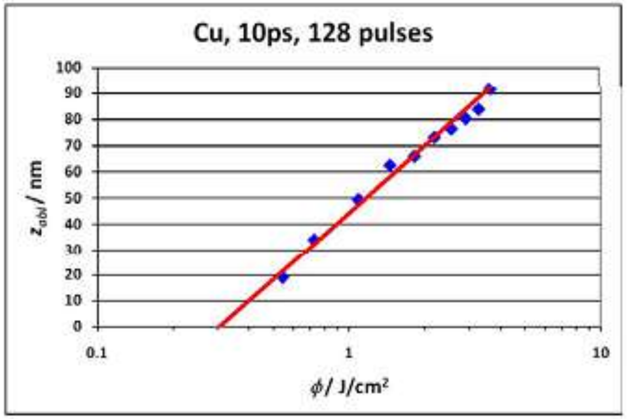
Bern University of Applied Sciences

Institute for Applied Laser, Photonics and Surface Technologies ALPS

Experimental Set-Up

- fs Laser System SATSUMA, λ = 1030 nm
- Beam quality $M^2 \leq 2.0$, waist radius w_0=13.5 µm → assumed Gaussian shaped
- Focal plane on the target surface
- 1 kHz to avoid heat accumulation





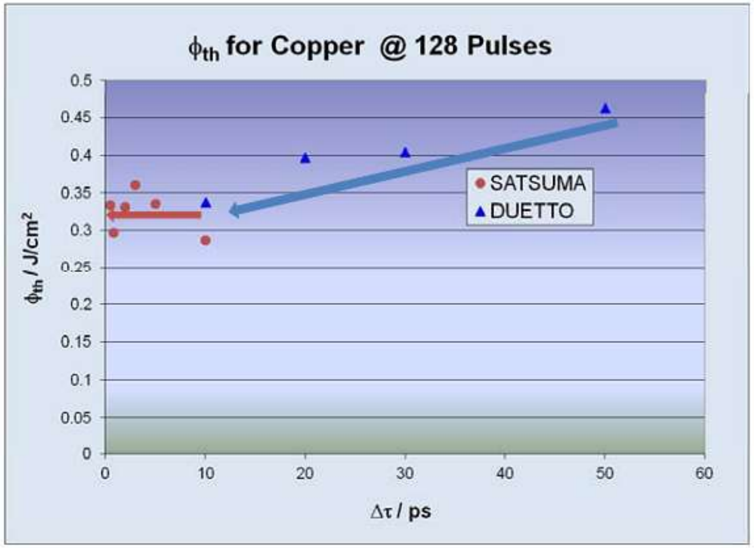
Least square fit:

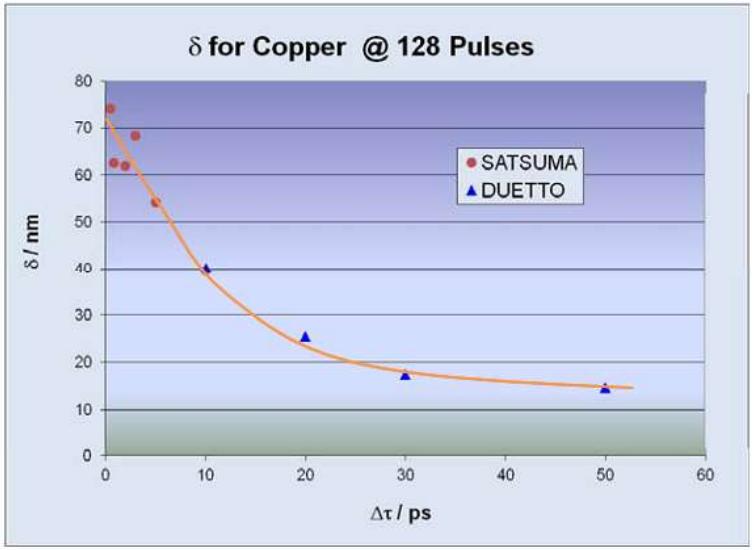
ϕ_{th} = 0.3 J/cm² δ = 37 nm

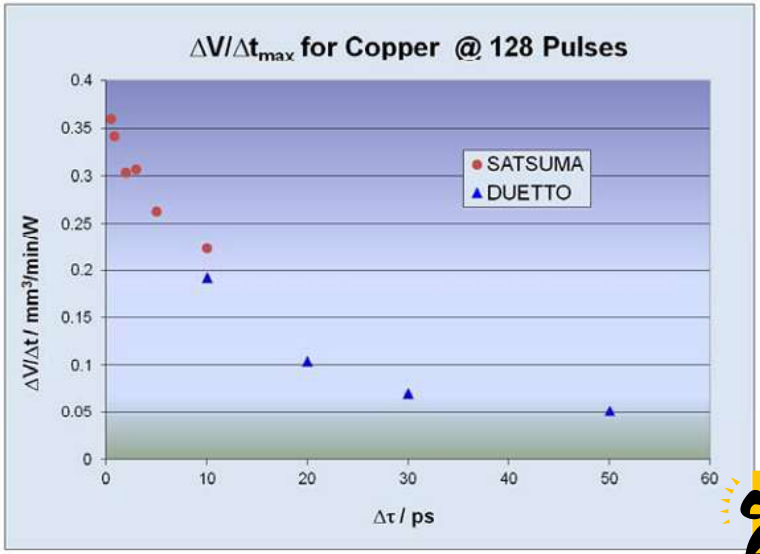
The parameters ϕ_{th} and δ were deduced for:

- 500fs, 800fs, 2ps, 3ps, 5ps and 10ps pulse duration
- 1,2,4,8,….,512 pulses
- Copper and Steel

Results: Copper

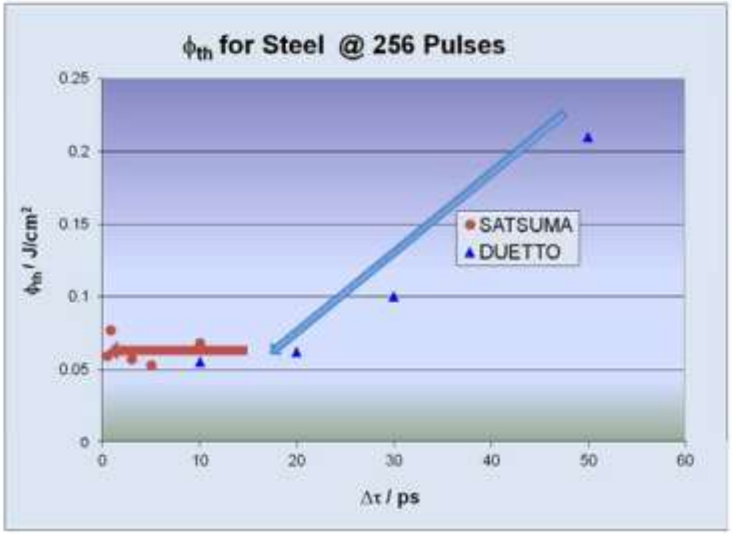


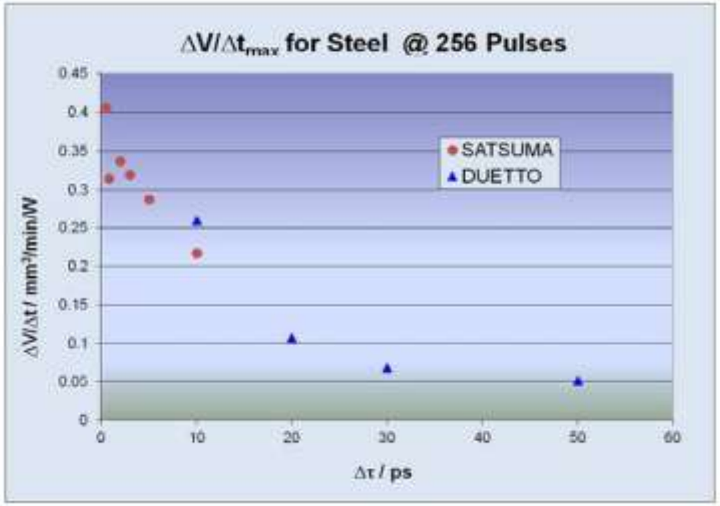




- Threshold slightly decreases when the pulse durations is reduced from 50ps to 10ps and rests almost constant for shorter pulses.
- A continuous increase of the penetration depth is observed when the pulse duration is reduced from 50ps to 500fs
- Continuous grow of the maximum volume ablation rate by reducing pulse duration

Results: Steel





Same behaviour with Steel

Ps versus fs processing quality

ALPhA NOV
Optics & Lasers Technology Center

Bern University of Applied Sciences
Institute for Applied Laser, Photonics and Surface Technologies ALPS

Results: Copper

128 pulses at $\phi_0 = 0.4\ J/cm^2$

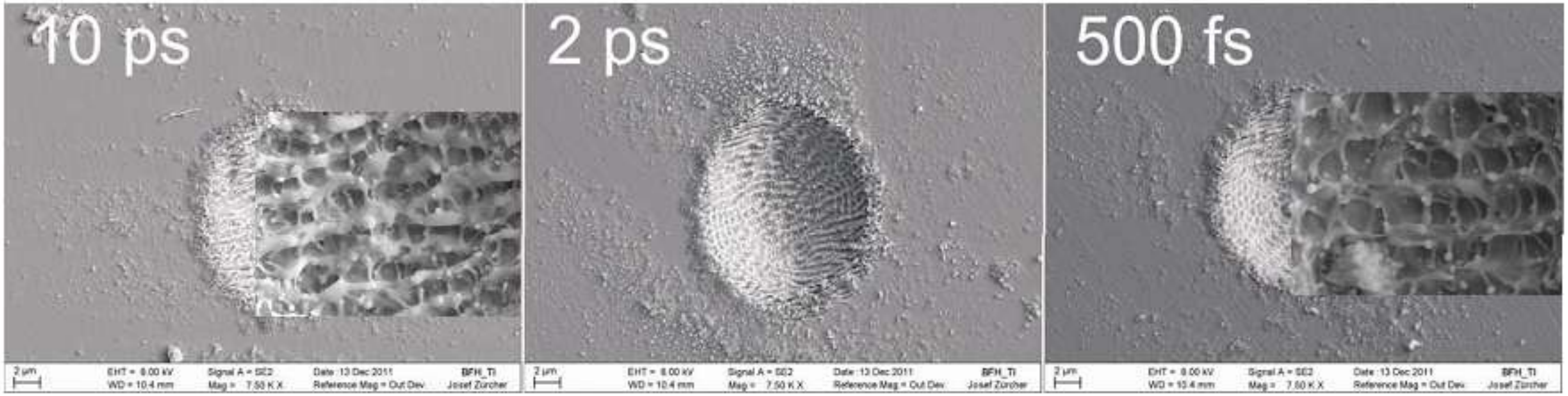
Deeper craters for shorter pulse durations (as expected).

Small worms of melted material are observed (-> regime dominated by electron diffusion).

These heat effects seem not to be significantly reduced by shorter pulse durations down to 500 fs.

Amplitude SYSTEMES

Results: Steel



256 pulses at ϕ_0 = 0.2 J/cm^2

Deeper craters for shorter pulse durations (as expected).

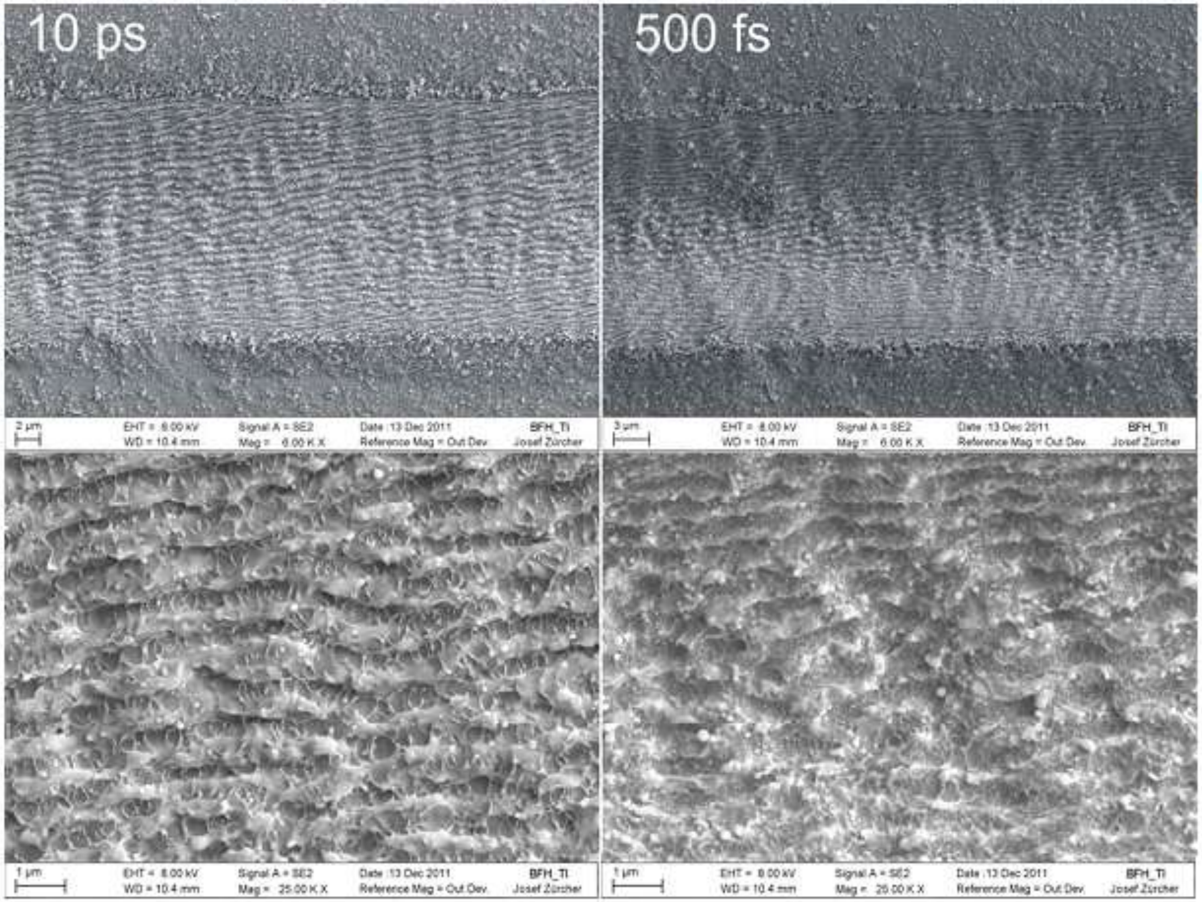
Ripple formation is observed for all investigated pulse durations from 10 ps down to 500 fs.

Melted material on and worms of melted material between the ripples are detected for the pulse duration of 10ps.

The metling effects are significantly reduced for the pulse duration of 500fs.

Amplitude SYSTEMES

Results: Steel



15 repeats

P_{av} = 170mW

f_{Rep} = 100kHz

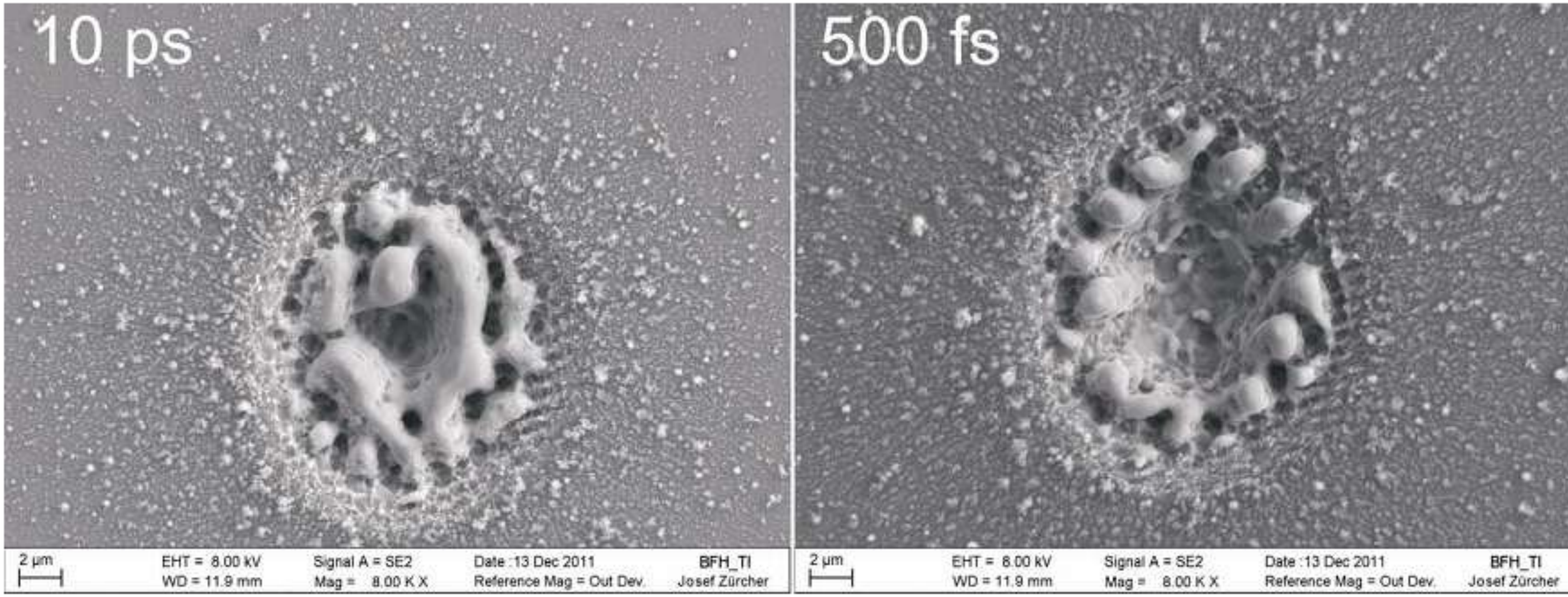
v = 160mm/s

-> ϕ_0 = 0.63 J/cm^2

pitch = 1.6 μm

Small worms of melted material are observed between the ripples for a pulse duration of 10ps. These worms are significantly reduced for 500fs pulse duration.

Results: Undoped Silicon



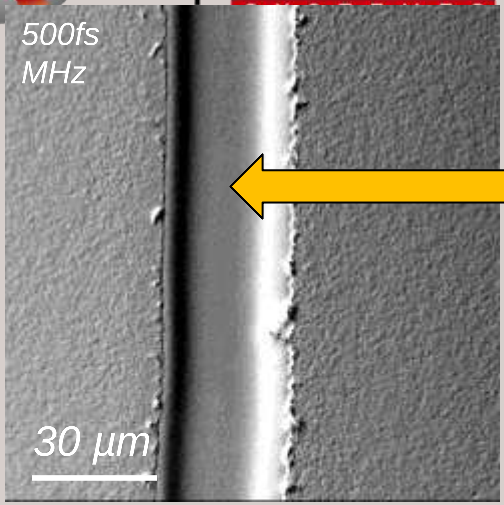
64 pulses at ϕ_0 = 0.57 J/cm^2

Crater / cone formation an melting effects are observed for all investigated pulse durations.

Reduced melting effects for 500fs compared to 10ps.

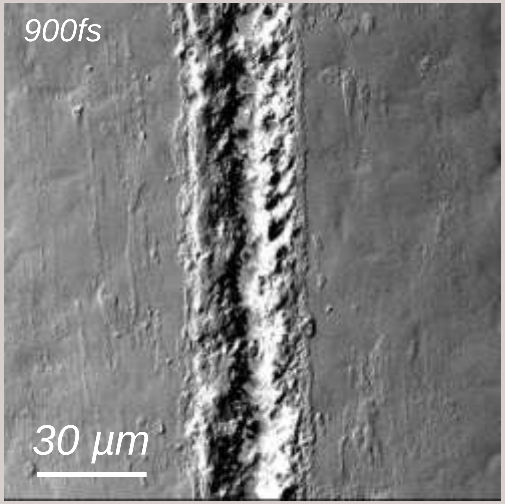
Pico-femto comparison

On Silicon

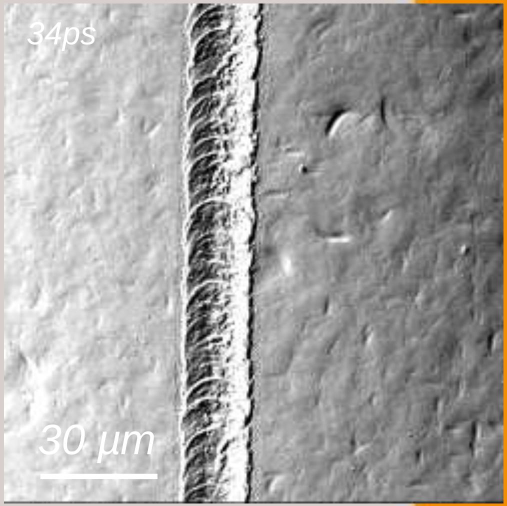


Smooth (melted layer?)

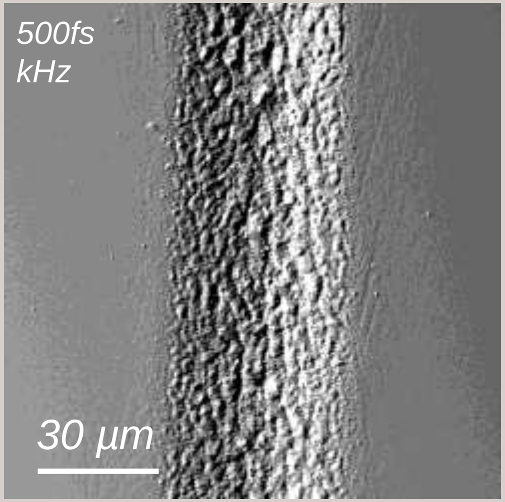
12W@2MHz 500mm/s
Depth 3.5µm



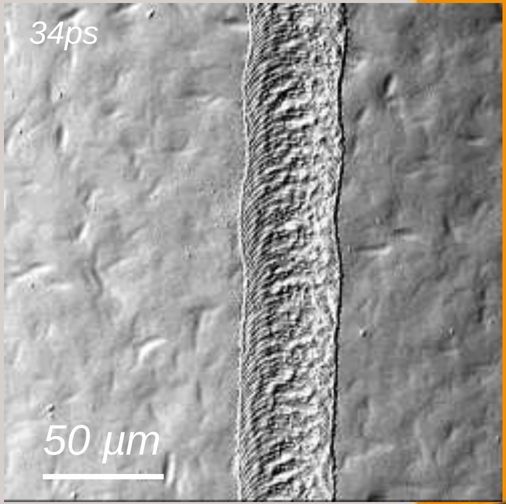
1W@200KHz 20mm/s
Depth 7µm



14W@200kHz 100mm/s
Depth 3.6µm



6W@200kHz 200mm/s
Depth 4µm



14W@200kHz 500mm/s
Depth <1µm

Conclusion on ps / fs comparison

- In ultrafast regime shorter pulse duration offers a better process efficiency

- In ultrafast regime quality of process is dependent on electron-phonon coupling time of the target material (0,5ps for Fe – 50ps for Cu)

- Femtosecond laser are now ready for industrial applications and offers signficant advantages in front of picosecond laser

Amplitude SYSTEMES