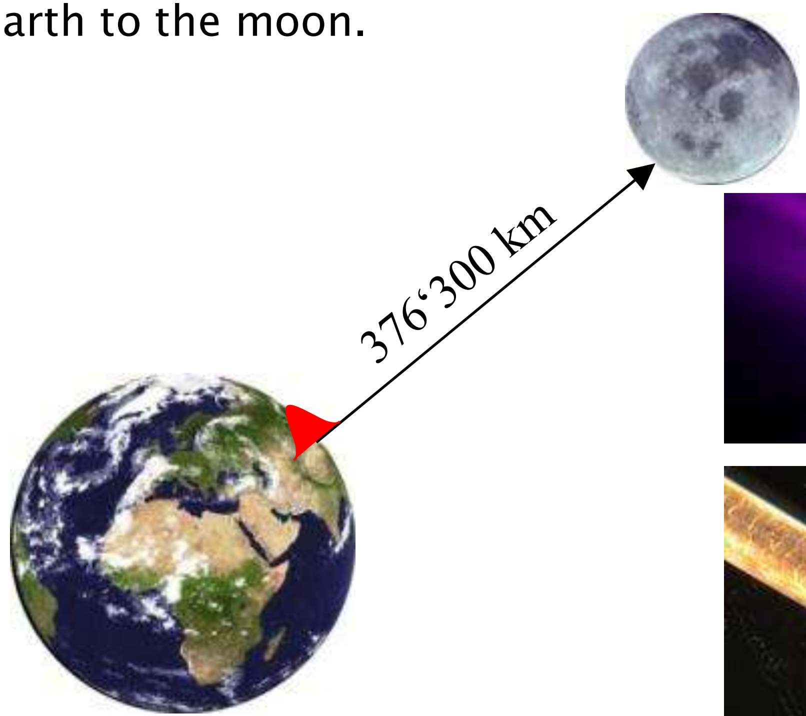
Berner Fachhochschule
Haute école spécialisée bernoise
Bern University of Applied Sciences

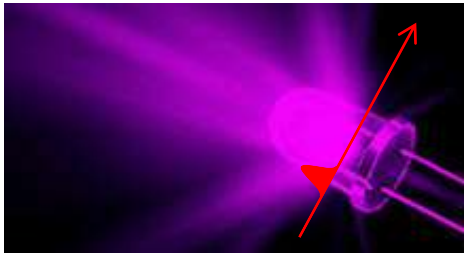
Ultra-short laser pulses in micro-processing: Myth, a next generation technology or already reality?

B. Neuenschwander

What means ultra-short?

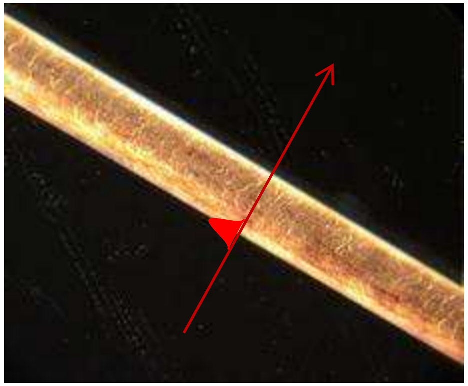
Light needs 1.25s for travelling the distance from the earth to the moon.





The diameter of a small LED amounts 3 mm:

For travelling 3 mm light needs 10 ps ($10 \cdot 10^{-12}$ s)

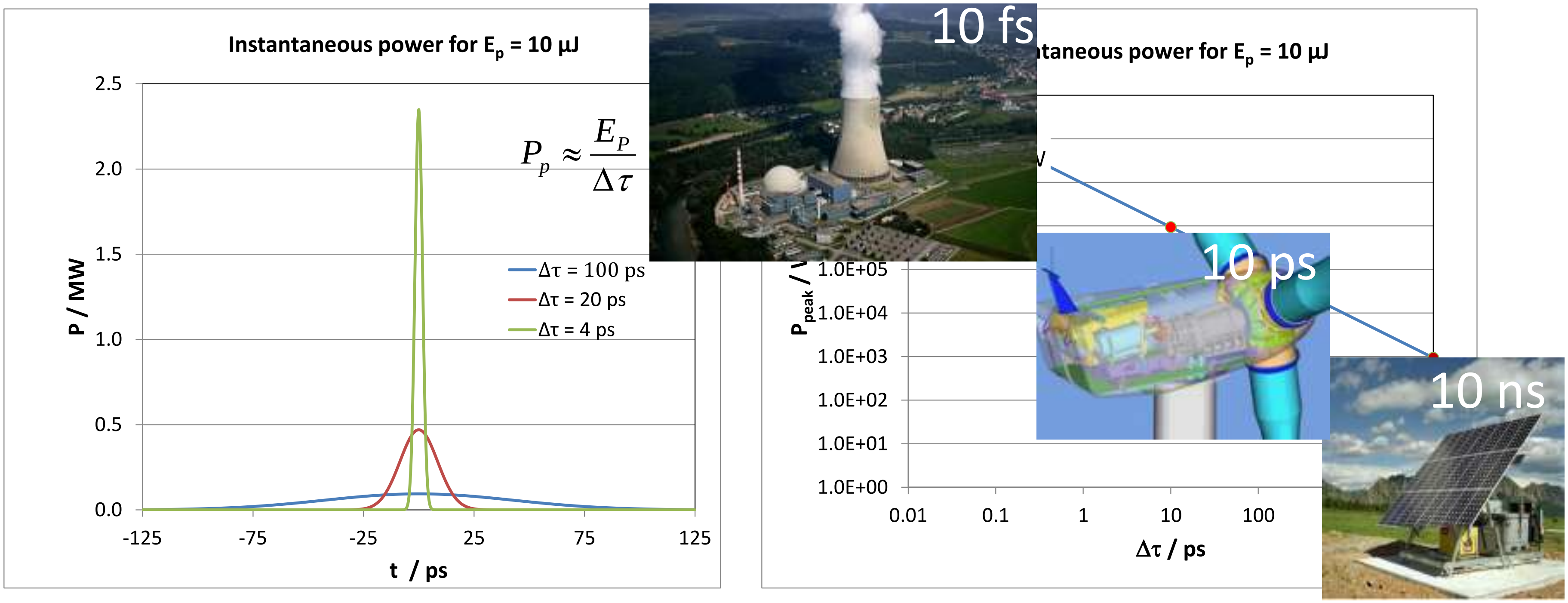


Human hair, thickness ca. 60 µm:

For travelling 60 µm light needs 200 fs ($200 \cdot 10^{-15}$ s)

Ultra-short laser pulses are really short!

What means ultra-short?

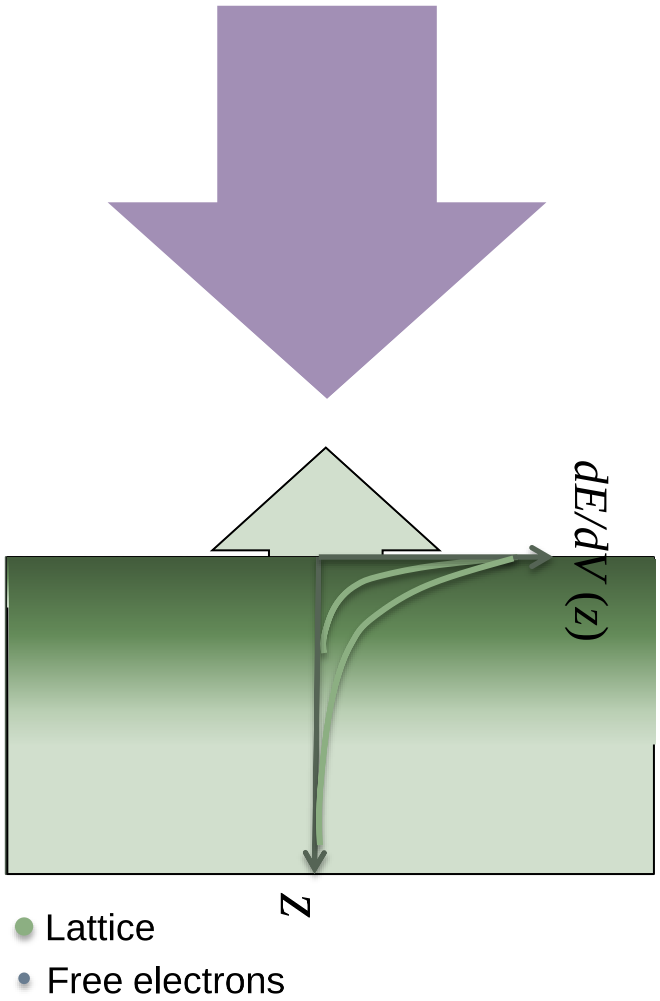


Even with small pulse energies huge peak powers can be achieved with ultra-short pulses.

Laser – Matter interaction times (metals)

1 fs	Heating of free Electrons
100 fs	Relaxation of the Electrons
<10 ps	Heat Conduction of the Electrons
>10 ps	Electron – Lattice Interaction Heating of the lattice
	High Lattice Temperature Non Equilibrium State
1 ns	Electron – Lattice Equilibrium Evaporation

Model of the ablation process: Energy transport



The incoming laser pulse

- is absorbed by the free electrons
- the energy is transferred to the lattice
- and the material is removed (ablated)

The energy transport into the material is described with the two temperature model.

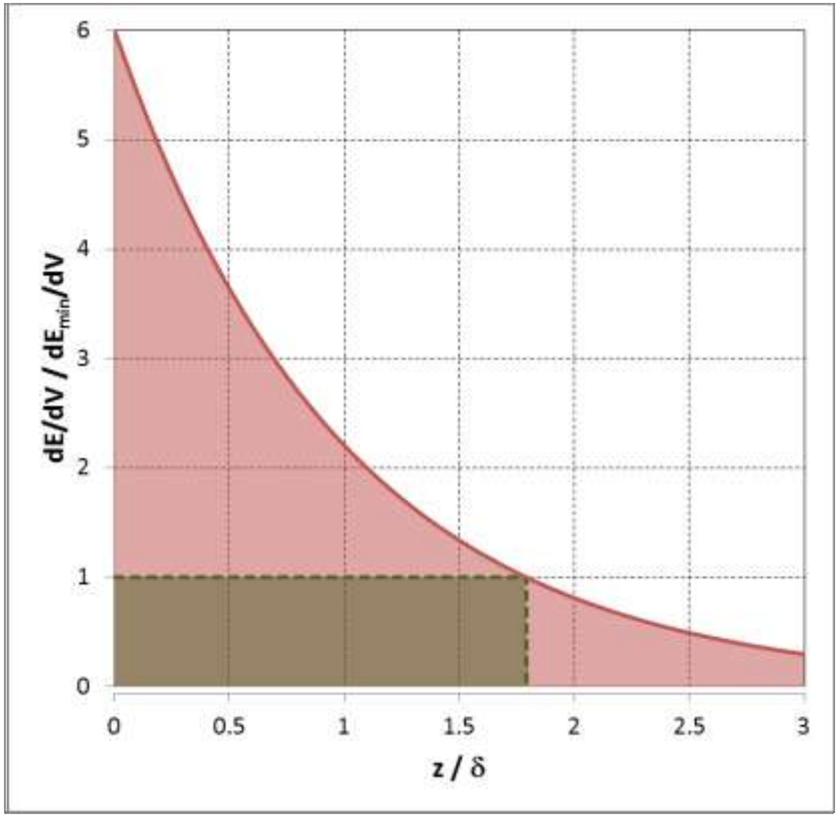
The deposited energy per volume exponentially drops with the distance to the surface. Depending on the pulse duration and the applied fluence the corresponding penetration depth is dominated by

- optical penetration depth

or by the

- the thermal diffusion length of the free electrons

Top Hat: Ablation Efficiency



The deposited energy per unit volume exponentially drops with the distance z to the surface.

$$\frac{dE}{dV}(z)=\frac{dE_0}{dV}\cdot e^{-\frac{z}{\delta}}$$

To evaporate the material a minimum energy per unit Volume $\rho\cdot\Omega_{vap}$, is required, which defines the ablation depth

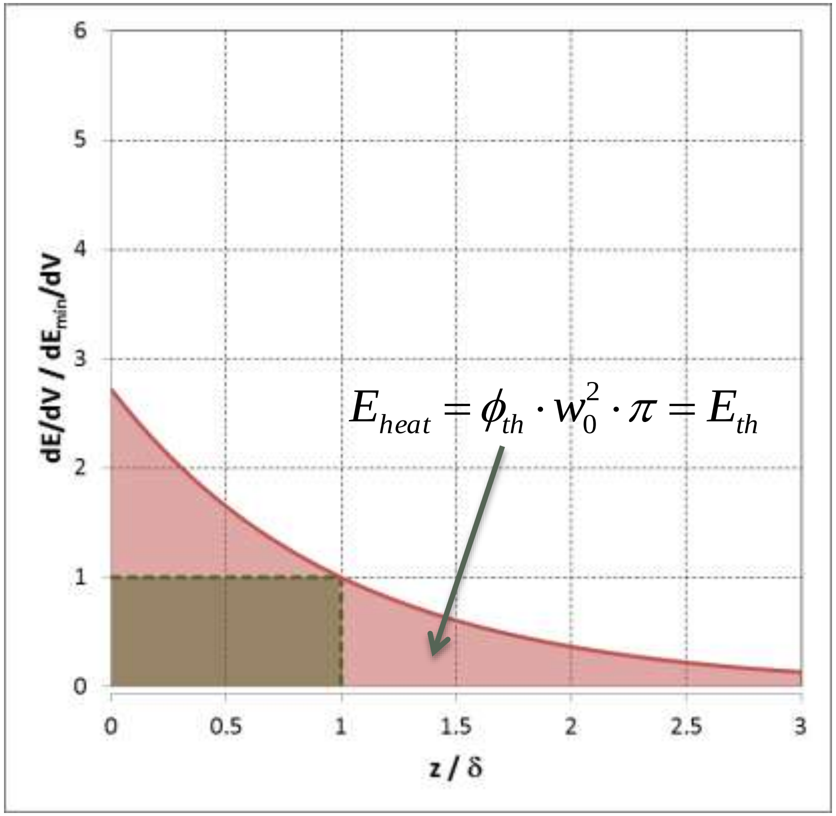
$$z_{abl}=\delta\cdot\ln\left(\frac{\phi}{\phi_{th}}\right)$$

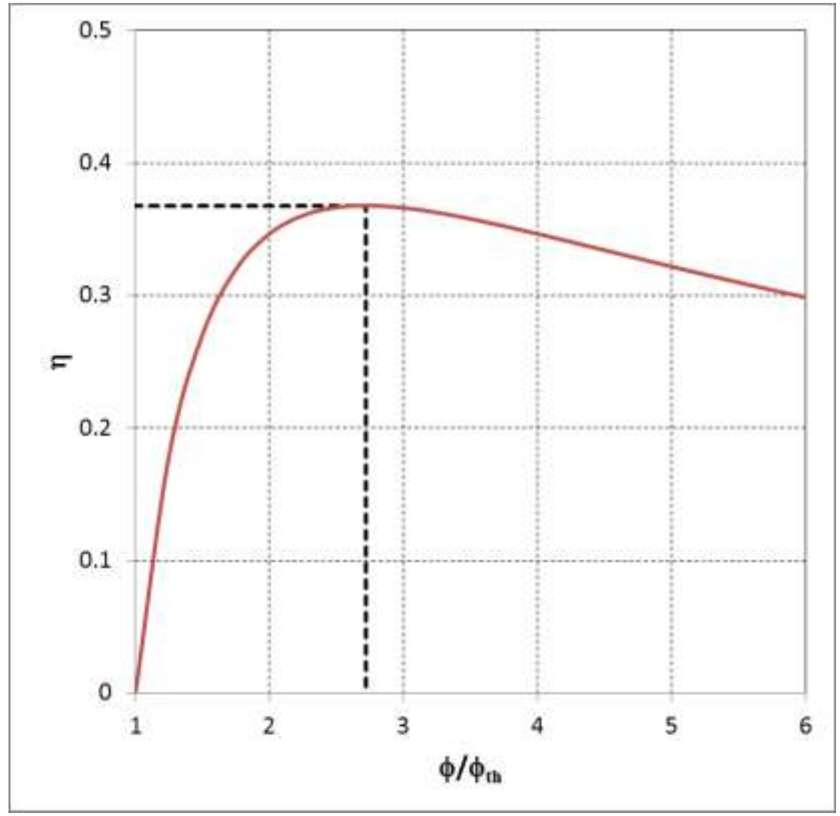
The totally deposited energy corresponds to the red area under the curve, but only the green part is really needed.

The efficiency of the ablation process can be defined by dividing the green by the red area.

$$\eta=\frac{\phi_{th}}{\phi}\cdot\ln\left(\frac{\phi}{\phi_{th}}\right)$$

Top Hat: Ablation Efficiency



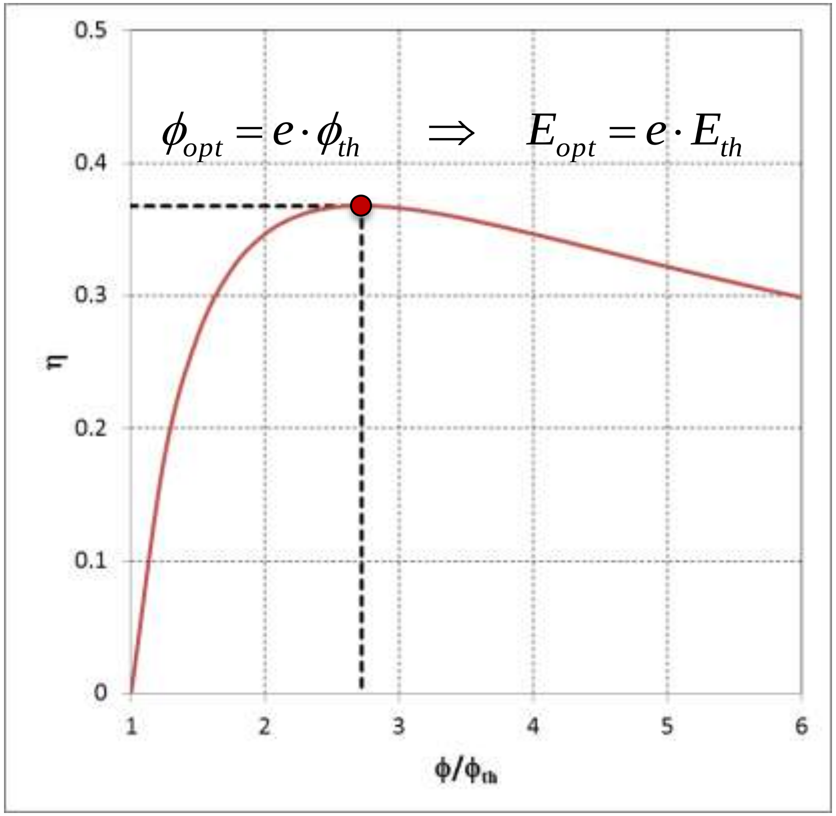


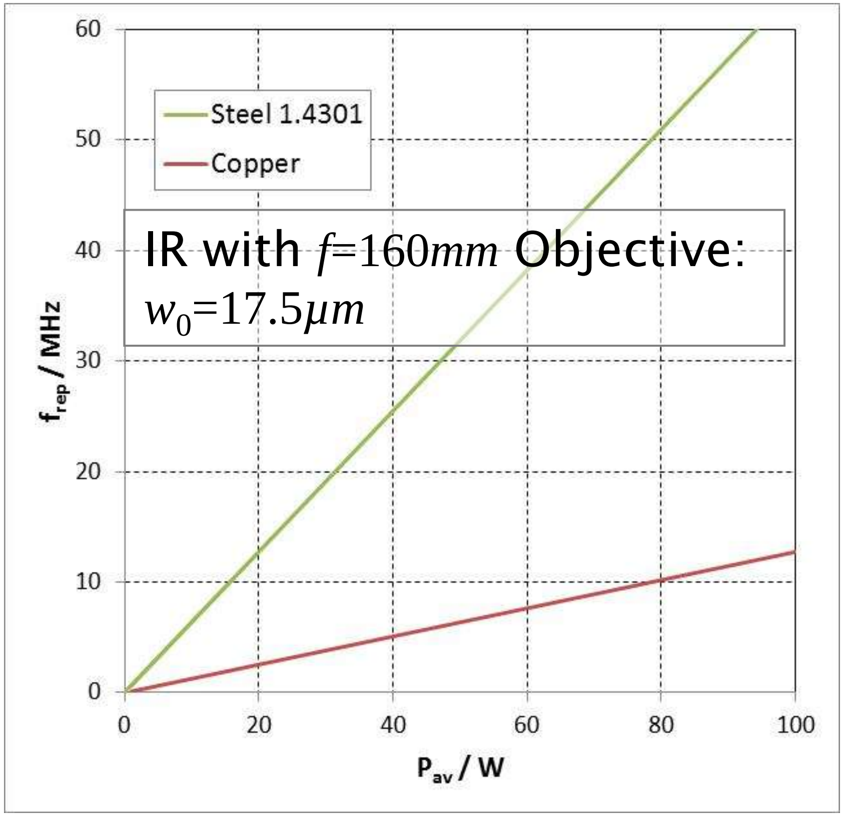
The efficiency η shows a maximum with: $\eta = 1/e = 36.8\%$ and $\phi = e \cdot \phi_{th}$

The ablation depth and volume per pulse then read: $z_{abl} = \delta$

The deposited energy is independent of the pulse energy

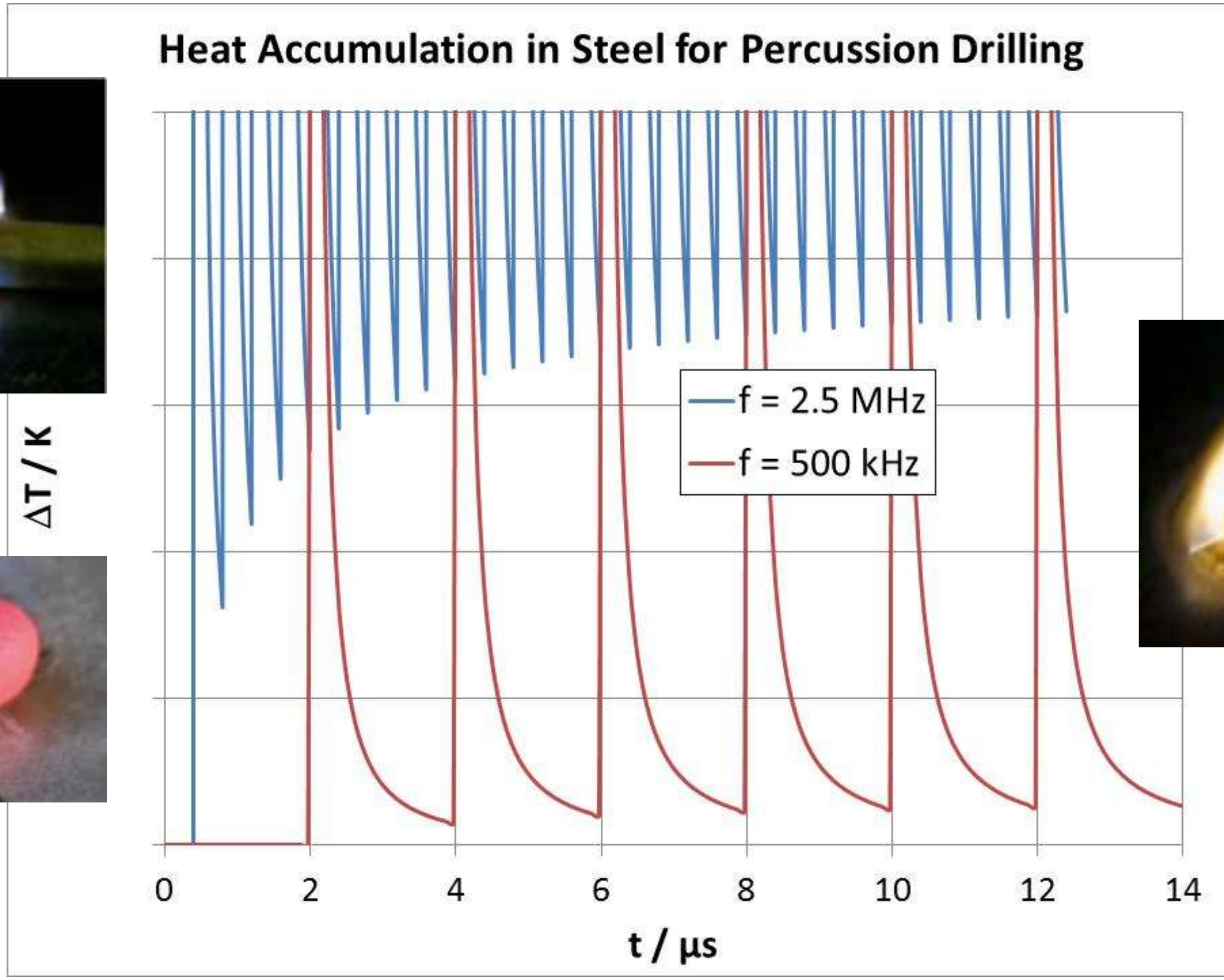
Top Hat: Optimum Point with Maximum Efficiency





Already at low average powers high repetition rates are demanded to work at the optimum point with maximum efficiency.

Heat Accumulation versus «Cold Ablation»



For ultra-short pulses “cold” ablation is a question of repetition rate and/or moving speed and not a general property.

Process – Material - Matrix

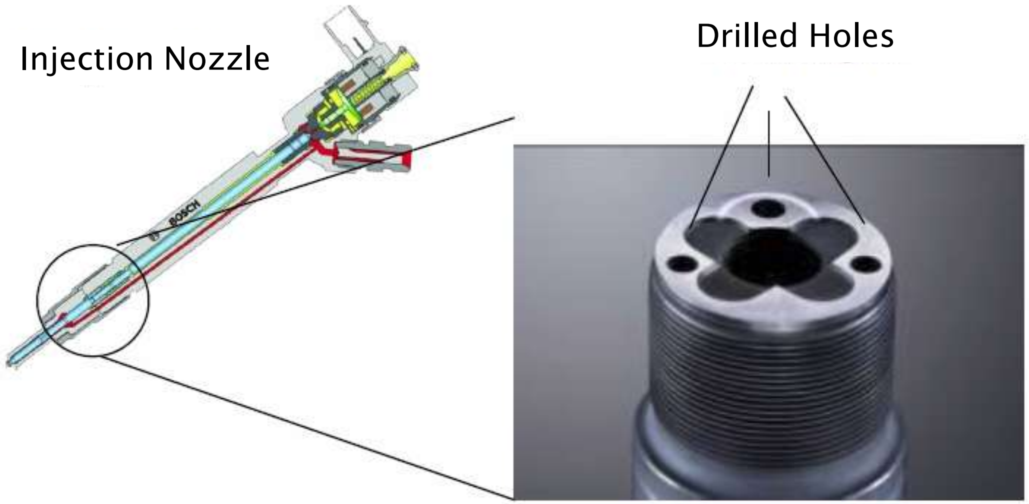
	Metals	Plastics	Glasses & Ceramics	Semiconductors
Master forming				
Shaping				
Separation	Drilling / Marking			
Joining				
Coating				
Material Properties				

Industrialized

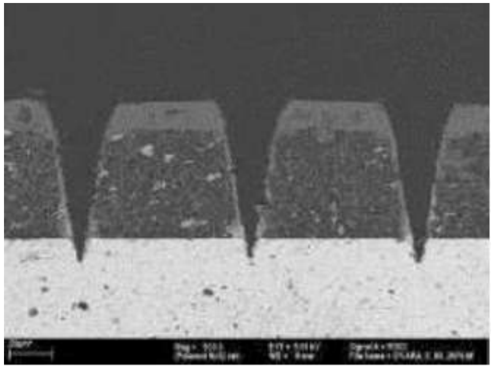
Industrial Applications

Examples from Bosch:

Drilling of Injection Nozzles:



Marking of defined grooves into a oxygen sensor.



Quellen: Bosch

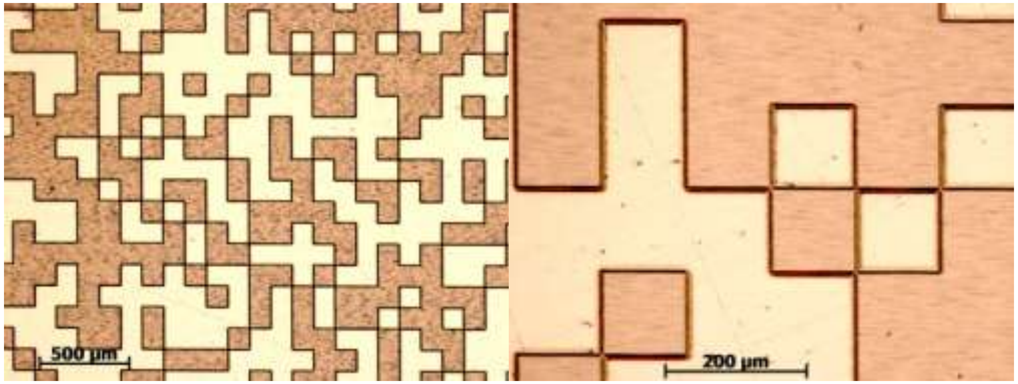
Process – Material - Matrix

	Metals	Plastics	Glasses & Ceramics	Semiconductors
Master forming				
Shaping				
Separation	Surface - structuring			
Joining				
Coating				
Material Properties				

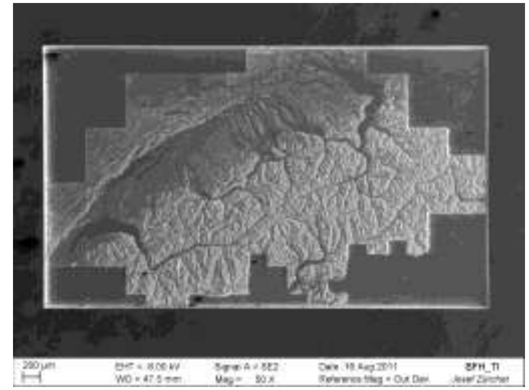
Industrialized & further research

Surface Structuring

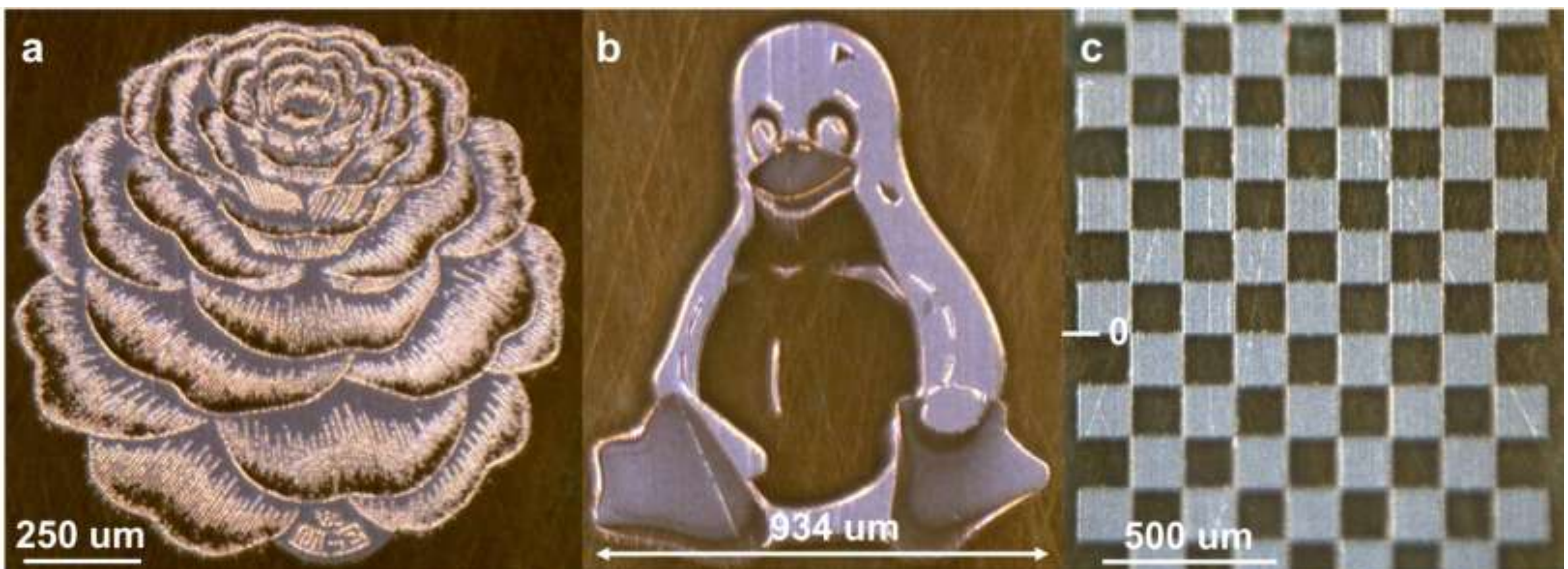
Marking of 2D matrix codes:



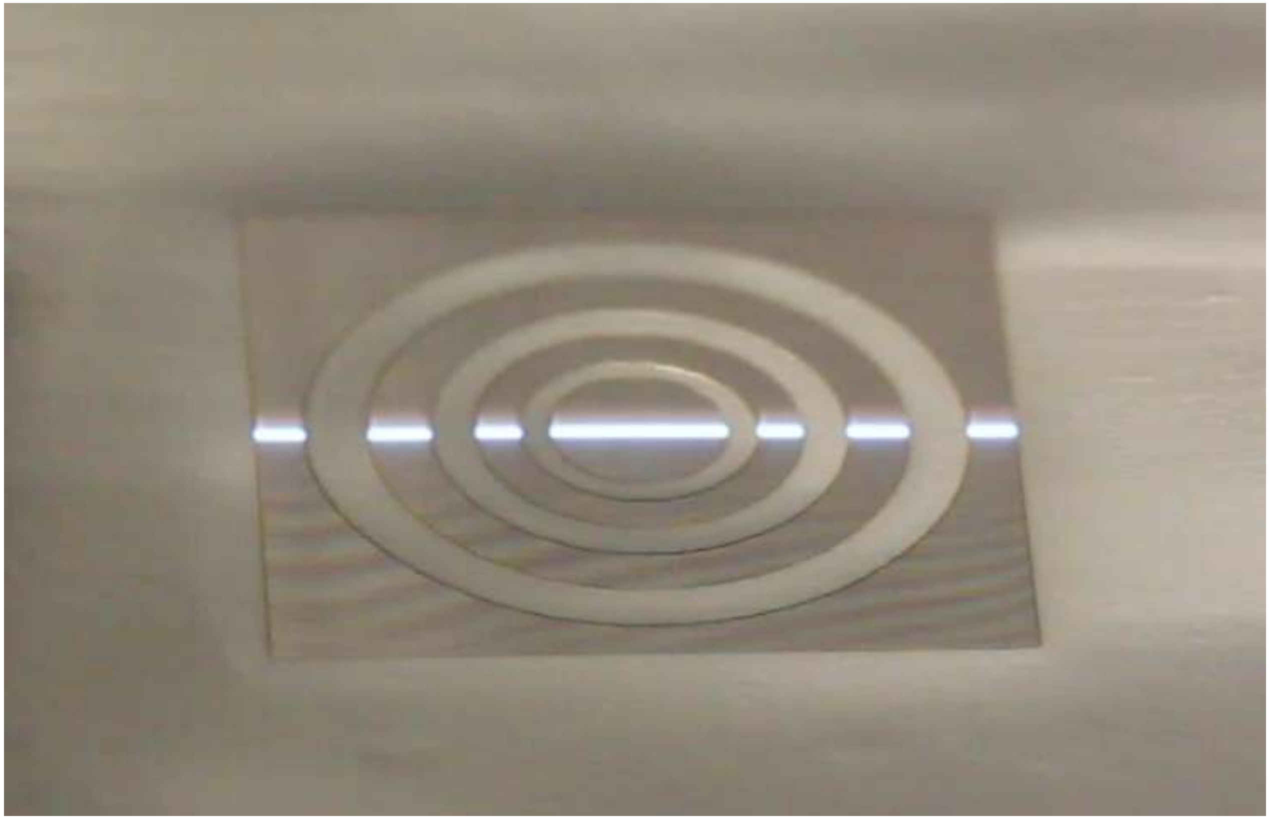
3D Structuring:



Synchronized marking on fast rotating cylinder:

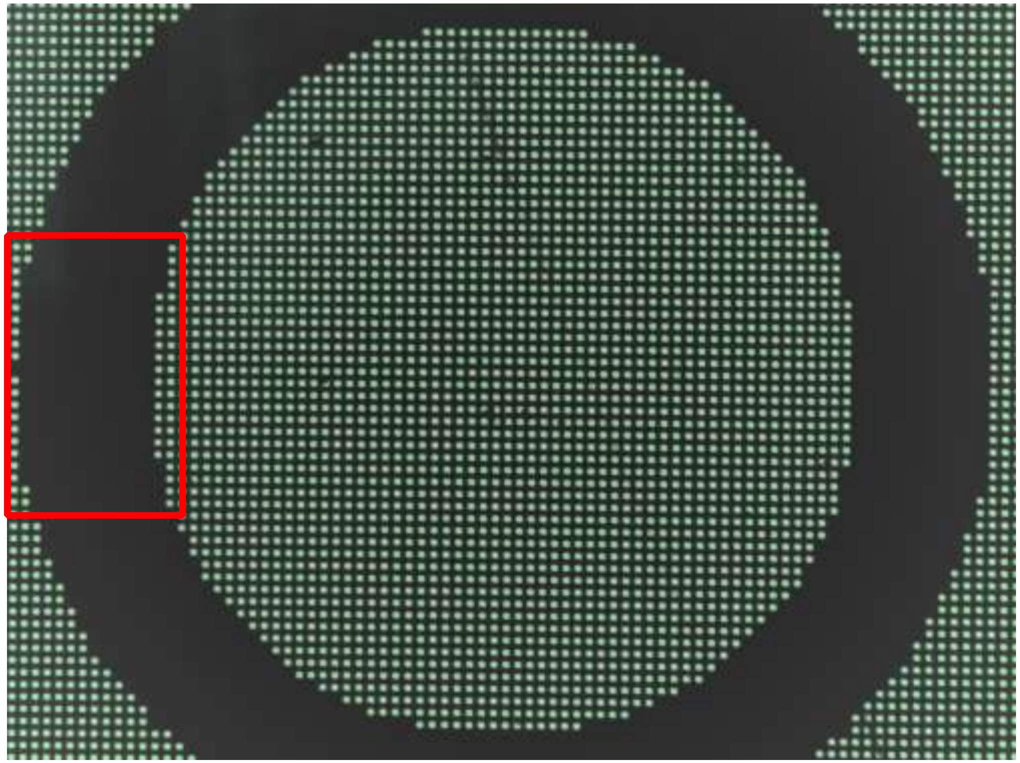


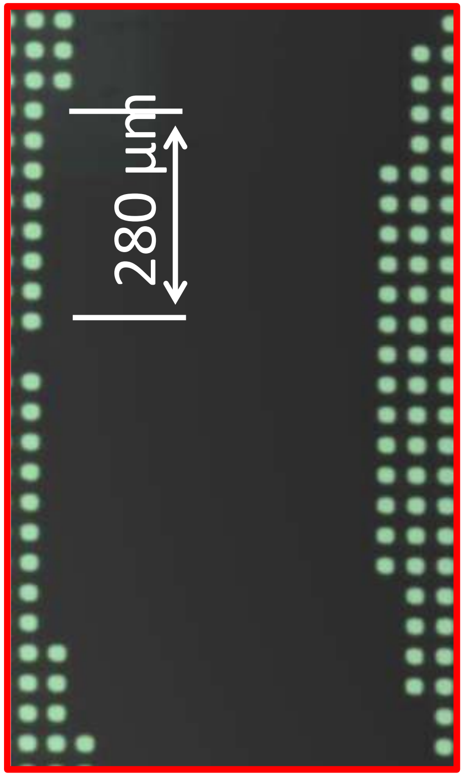
Multipulse Drilling on the Fly



Multipulse Drilling on the Fly

Multi-pulse drilling on the fly, 10 µm steel foil, 1064nm, 900 slices

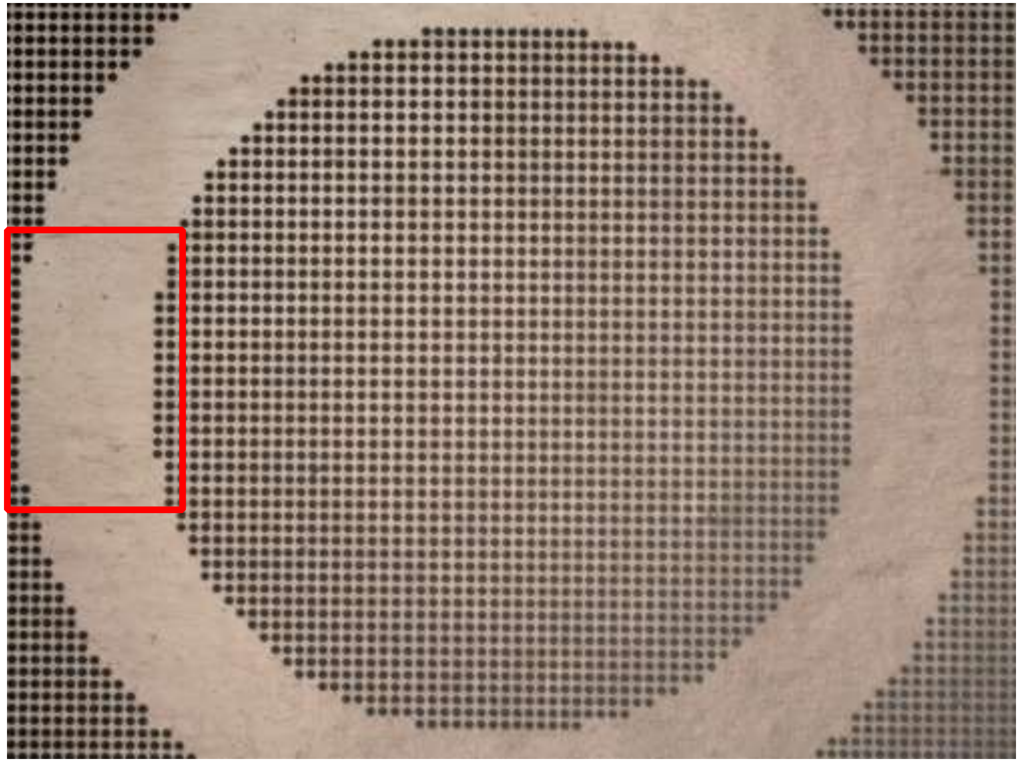


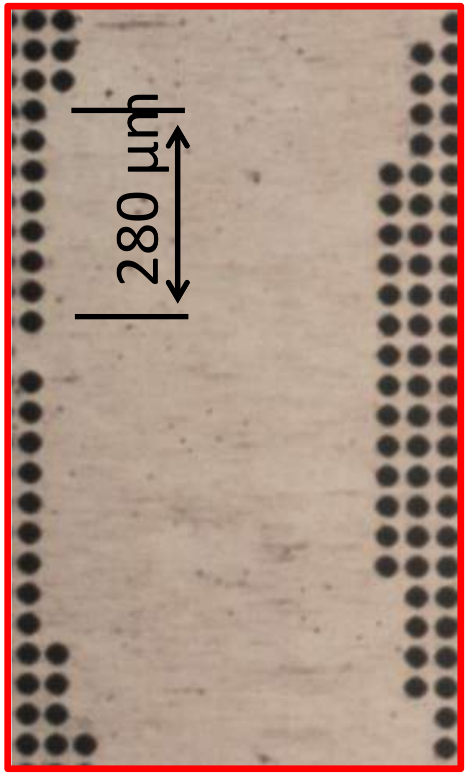


- Microscope image of the backside of the sample with green lighted from the frontside
- Every pixel correspond to one laser shot / drilled hole

Multipulse Drilling on the Fly

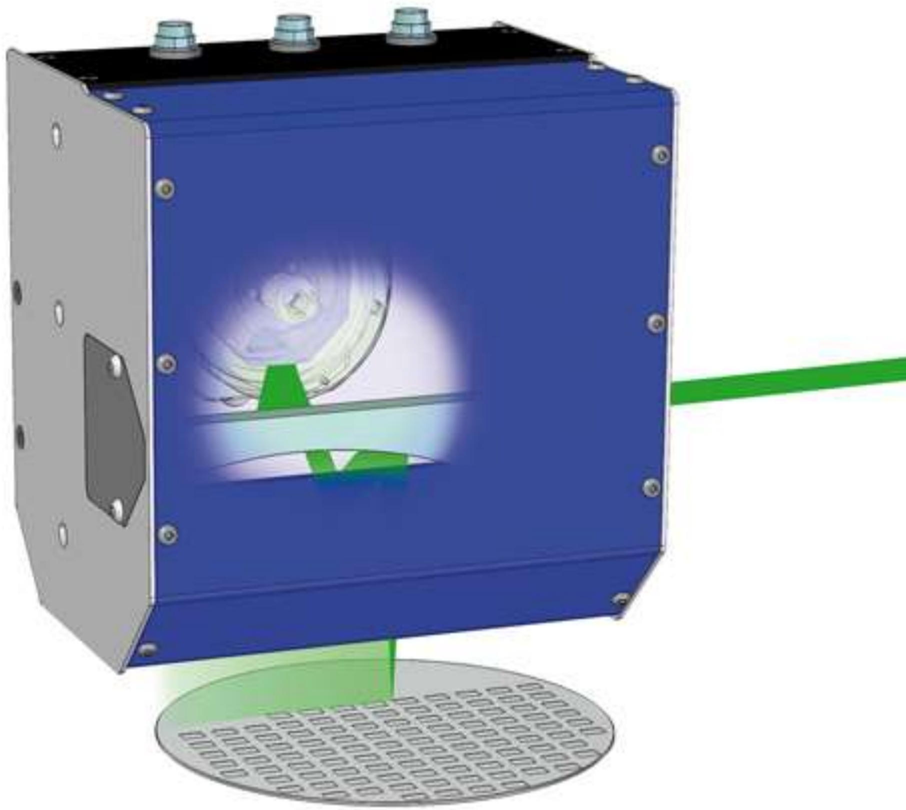
Multi-pulse drilling on the fly, 10 μm steel foil, 1064nm, 900 slices





- Reflected-light microscope image of the backside
- No deforming of the thin foil due to heat accumulation

Fast Synchronized Scanning with Polygon Scanner

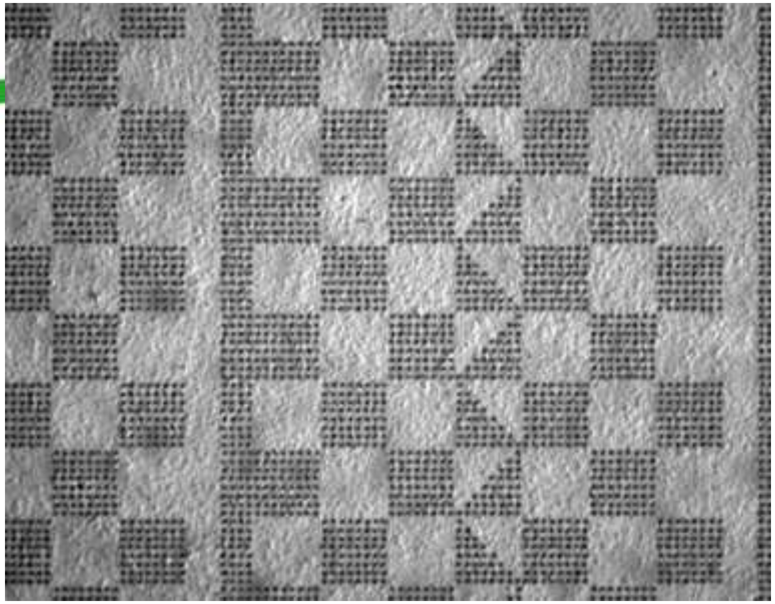


$$w_0 = 11\,\mu m \quad @ \quad \lambda = 532\,nm$$

$$w_0 = 22\,\mu m \quad @ \quad \lambda = 1064\,nm$$

$$\ell_{scan} = 170\,mm$$

$$v_{\max} = 100\,m/s$$



Synchronized with FUEGO from Time-Bandwidth Products AG

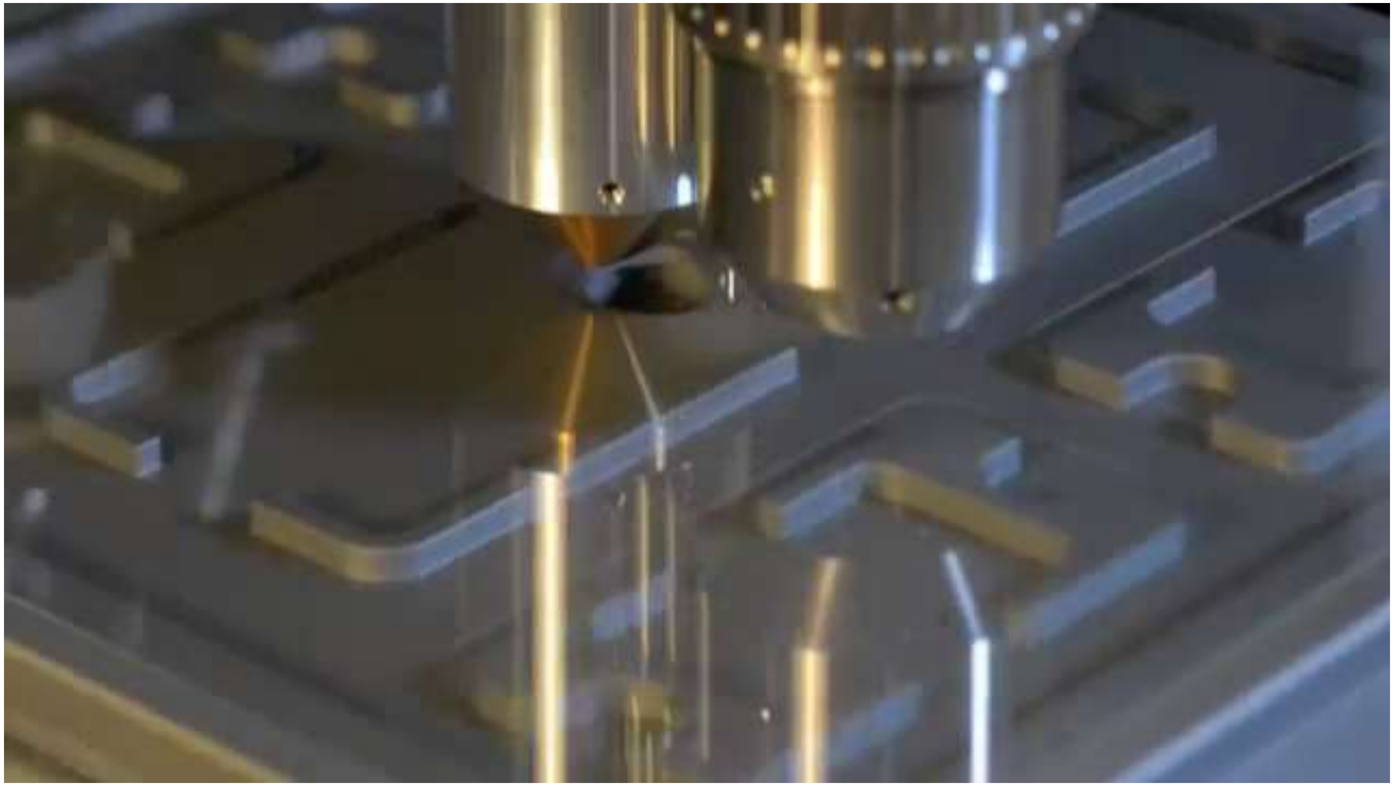
Fast Synchronized Scanning with Polygon Scanner

Process – Material - Matrix

	Metals	Plastics	Glasses & Ceramics	Semiconductors
Master forming				
Shaping				
Separation	Surface - structuring		Glas-Cutting	
Joining				
Coating				
Material Properties				

Industrialized & further research   Applied Research

Glass and Sapphire Cutting with Bursts



Quelle: Innolas

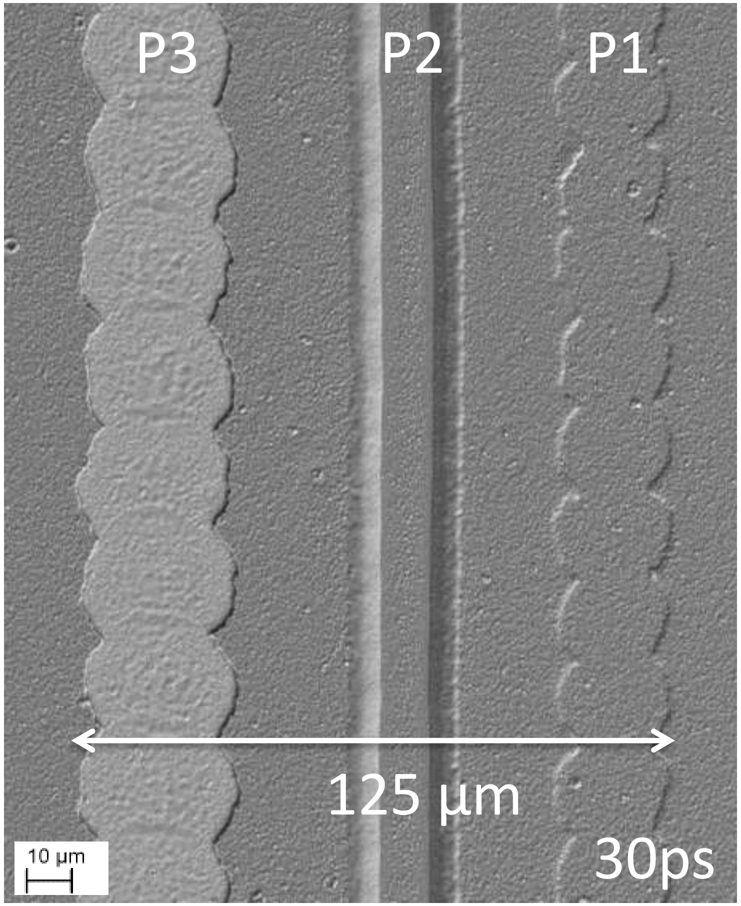
Process – Material - Matrix

	Metals	Plastics	Glasses & Ceramics	Semiconductors
Master forming				
Shaping				
Separation	Surface - structuring		Glas-Cutting	Laser Scribing of CIGS Solar Cells
Joining				
Coating				
Material Properties				

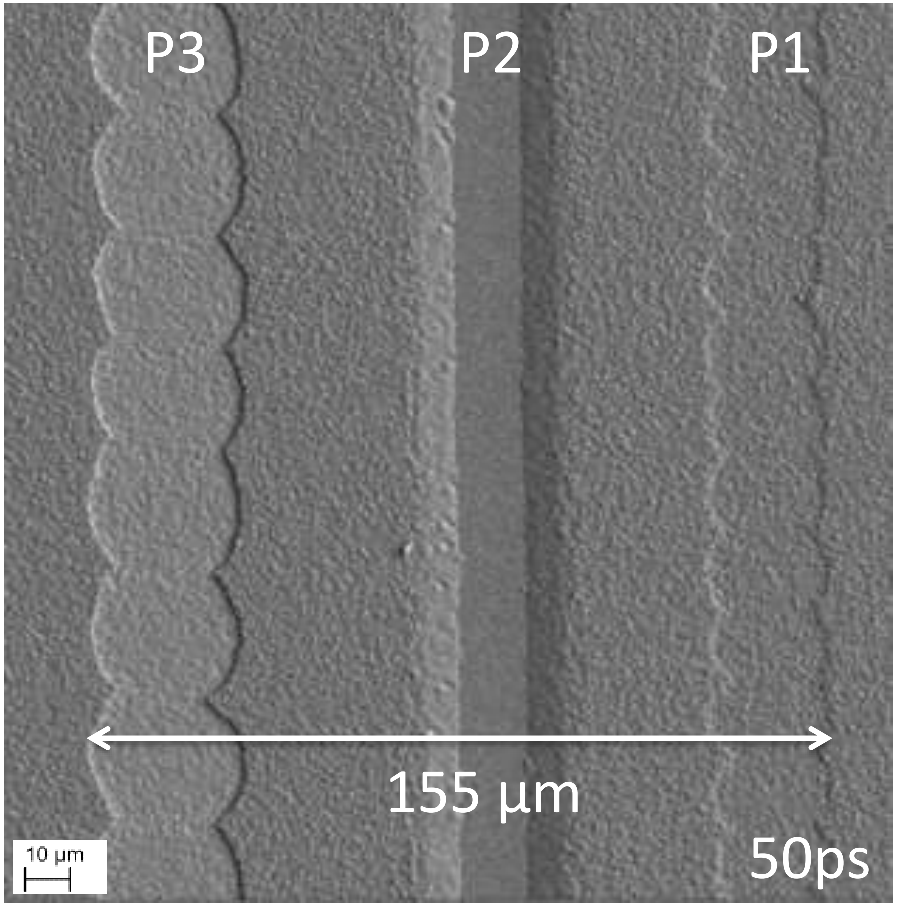
Industrialized & further research Applied Research

Scribing of CIGS Solar Cells

fiber laser



SSL



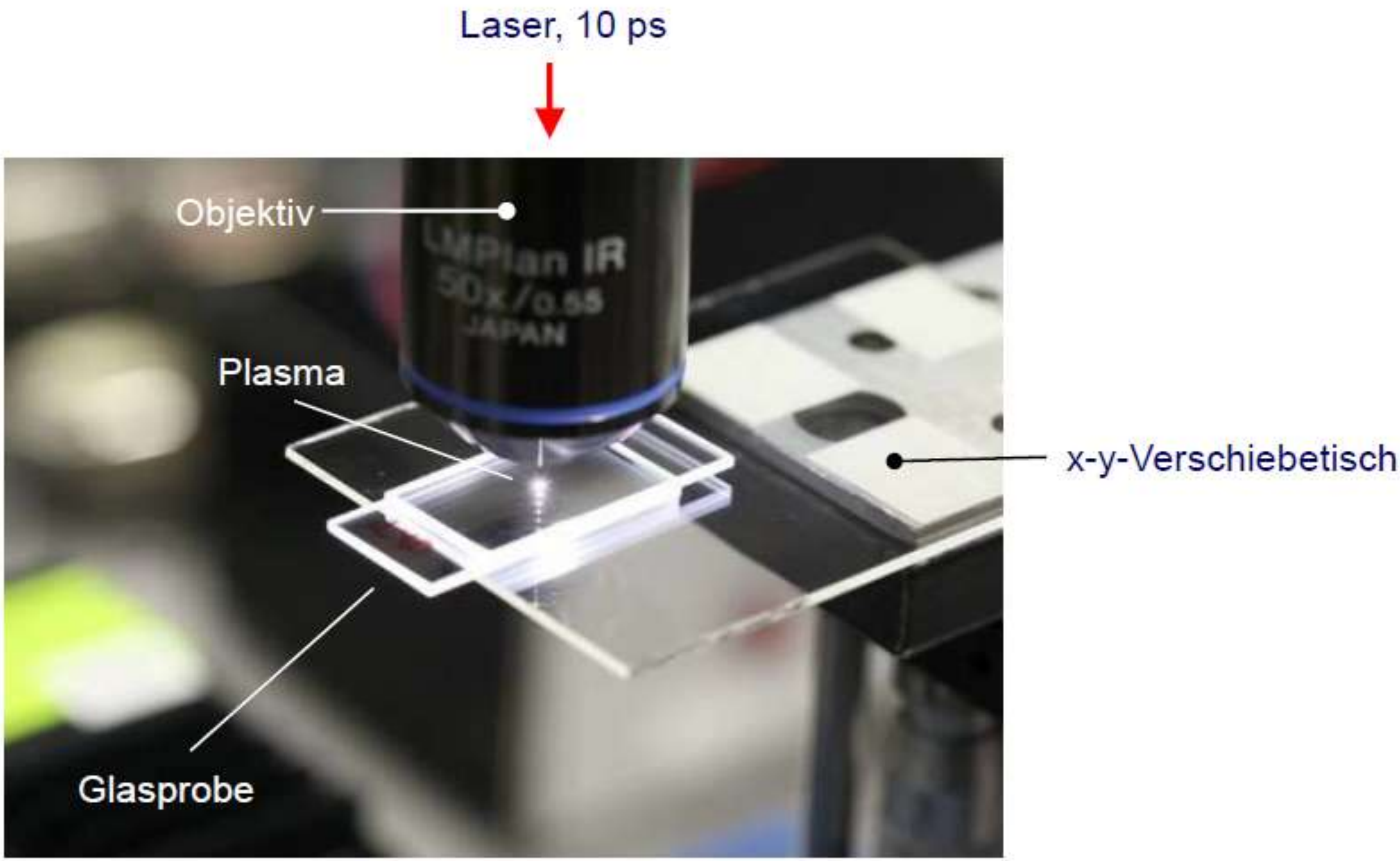
SEM image of complete module interconnect. Similar scribe quality is realized with SSL and fiber laser.

Process – Material - Matrix

	Metals	Plastics	Glasses & Ceramics	Semiconductors
Master forming				
Shaping				
Separation	Surface - structuring		Glas-Cutting	Laser Scribing of CIGS Solar Cells
Joining			Glass-welding	
Coating				
Material Properties				

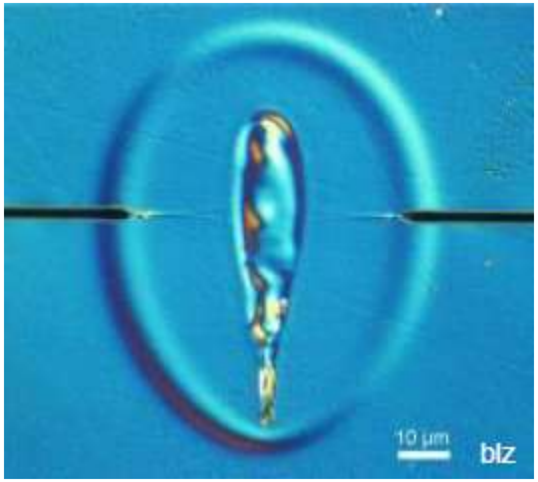
Industrialized & further research   Applied Research

Glass Welding



Quelle: Bayrisches Laserzentrum blz

Glass Welding



- Ultra-short pulses produce a plasma in the transparent glass
- The hot plasma rests within the glass
  - The plasma heats the environment
  - A high repetition rate guarantees a hot temperature
- The melting around the focal point welds the the single glasses

Process – Material - Matrix

	Metals	Plastics	Glasses & Ceramics	Semiconductors
Master forming				
Shaping	Microshock-wave shaping		Microshock-wave shaping	Microshock-wave shaping
Separation	Ablation / Sur-facestructuring	Surface Structuring	Ablation, Cutting, Surfacestructuring	Laser Scribing of CIGS Solar Cells, Structuring
Joining	Glass-Metal-Welding		Glass Welding	Glass-Semiconductor Welding
Coating			Coating with LIPPAA Process	
Material Properties			Waveguidescribing Inner Glass Marking	

Industrialized | Applied Research | Future Potential

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It‘s definitively not a myth

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Already existing industrialized processes

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Many processes are well on the way to successful industrialization

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Ultra-short laser pulses are also a promising technology for new applications

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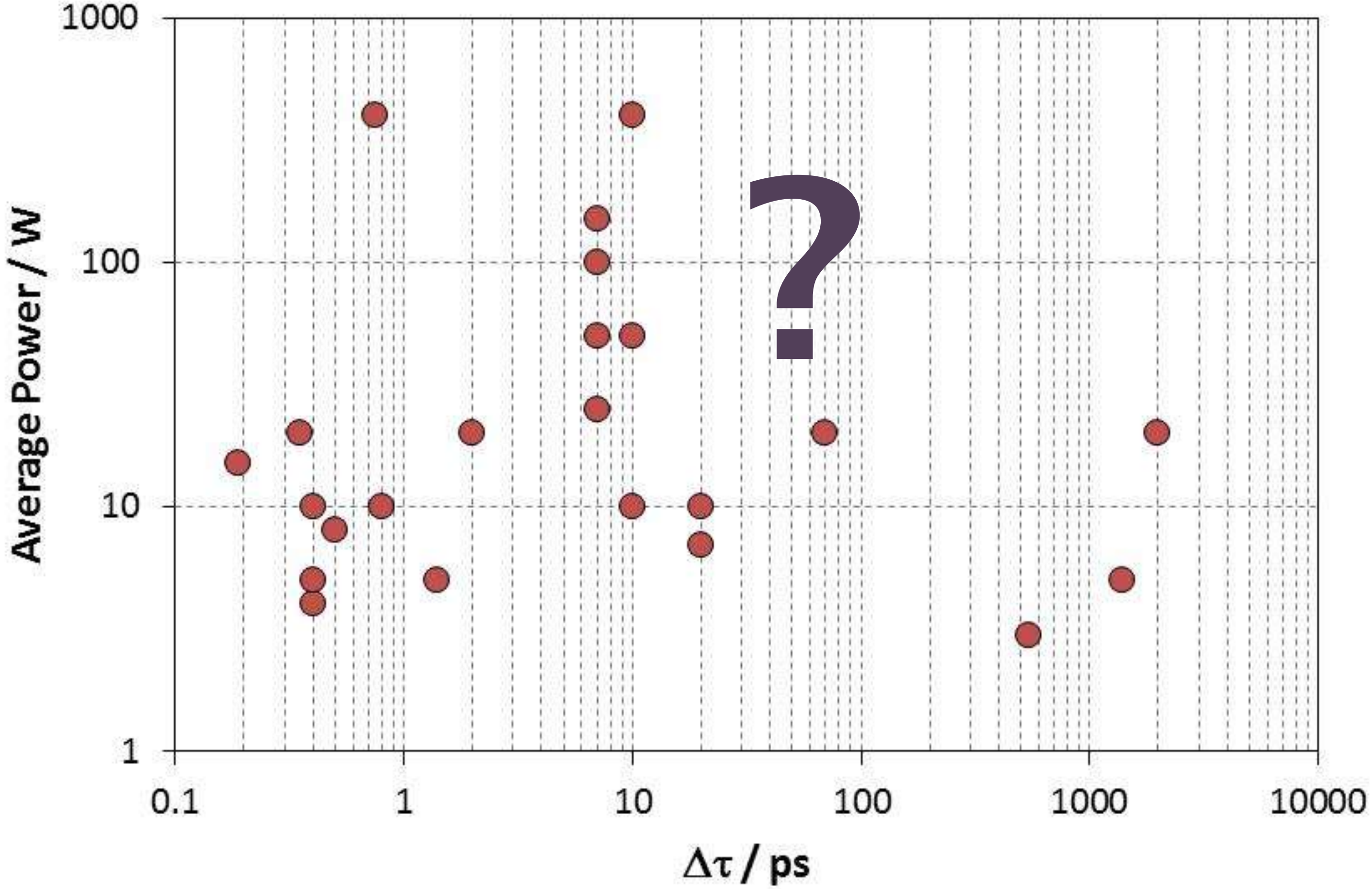
Ultra-Short Pulsed Systems



A lot of systems with different pulse durations, average powers, wavelengths and pulse energies exist on the market

SNAPP

Swiss **N**ational **A**pplication laboratory for **P**hotonic tools and **P**hotonic manufacturing

The main Swiss institutions in laser processing have decided to collaborate to offer the most suitable service to you.

SNAPP

Swiss **N**ational **A**pplication laboratory for **P**hotonic tools and **P**hotonic manufacturing

The Swiss material processing industry has expressed interest in a Swiss national application laboratory for photonic tools and photonic manufacturing (SNAPP) for the following reasons

- near proximity
- continuity of personnel
- protection of know how
- priority of access

The reason for the merger was the pooling of skills and equipment. Each partner has its core competencies. The group can provide extensive consulting and industry work and carry out in joint efforts demanding research projects.

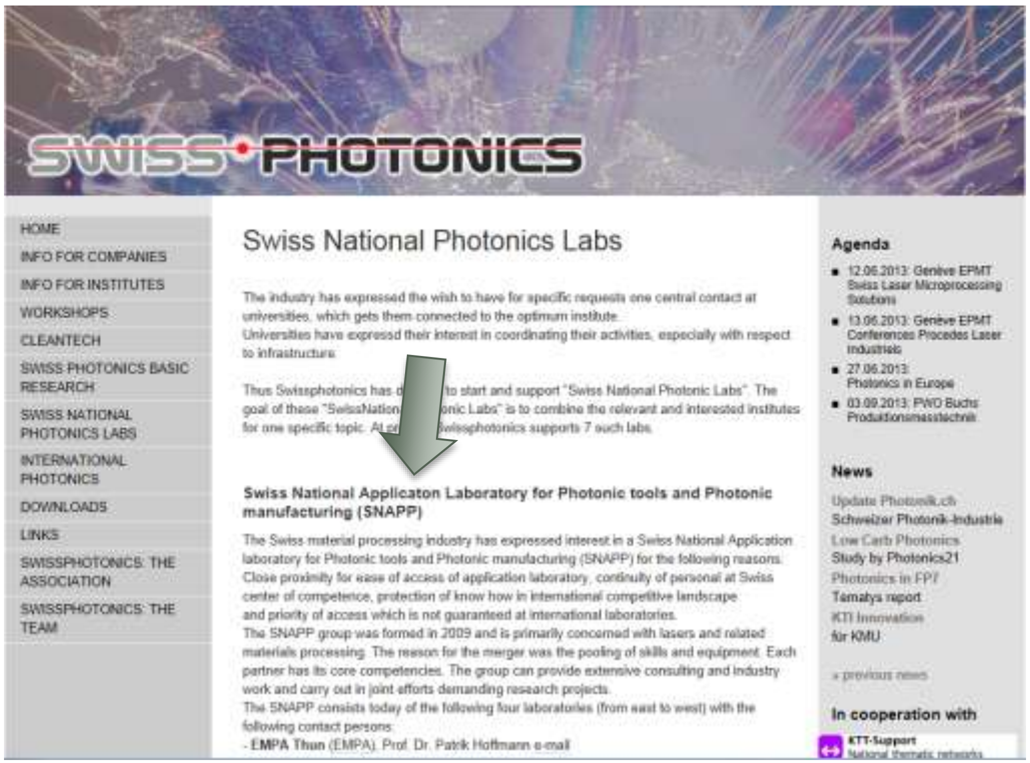
SNAPP

The SNAPP consists today of the following four laboratories (from east to west) with the following contact persons

- EMPA Thun and Dübendorf
  Microprocessing with Excimer and ps-Laser
  Prof. Dr. Patrick Hoffmann
- BFH Burgdorf
  Microprocessing with ultrashort laser pulses, process development and synchronization
  Prof. Dr. Beat Neuenschwander
- FHNW Windisch
  Microprocessing, 3D engraving, integration
  Beat Lüscher
- csem Alpnach
  UV-picosecond processing with industrial machine
  Dr. Janko Auerswald
- inspire ETH Zürich and irpd St. Gallen
  Laser Micro- and Macroprocessing
  Josef Stirnimann

SNAPP

- SNAPP has internal meetings in order to be able to provide optimum service to their customers.
- SNAPP will organize two workshops a year with specific laser processing topics.
- SNAPP will offer a single entry point for all of your questions.



- Go to: www.swissphotonics.net
- Select SWISS NATIONAL PHOTONCS LABS
- Find SNAPP information and contacts