Extreme precision laser micromachining with ps-pulses and synchronized beam delivery

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- Motivation
- Synchronization
- Experimental Results
- Conclusion

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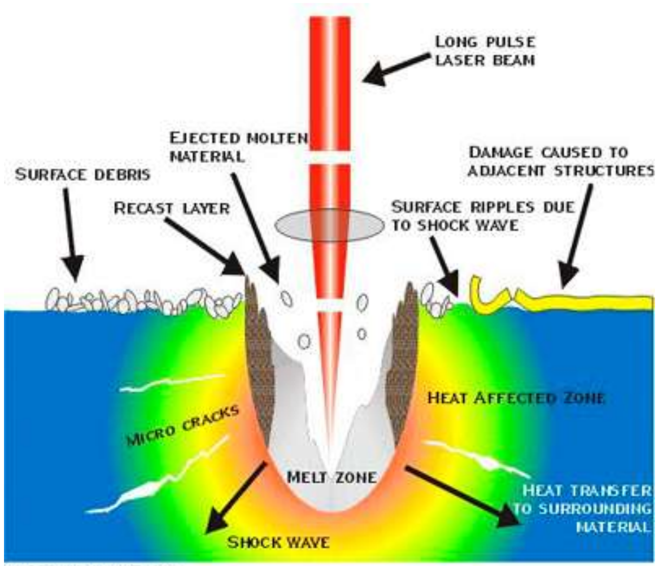
„Hot“ versus „cold“ ablation



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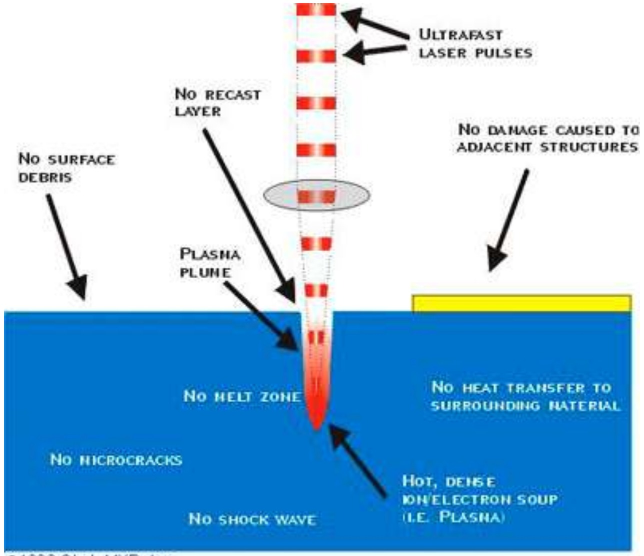

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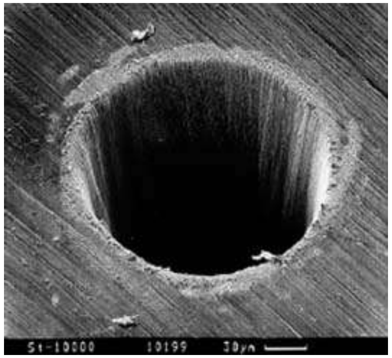
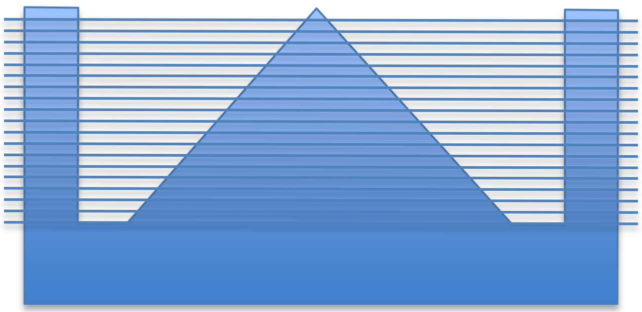


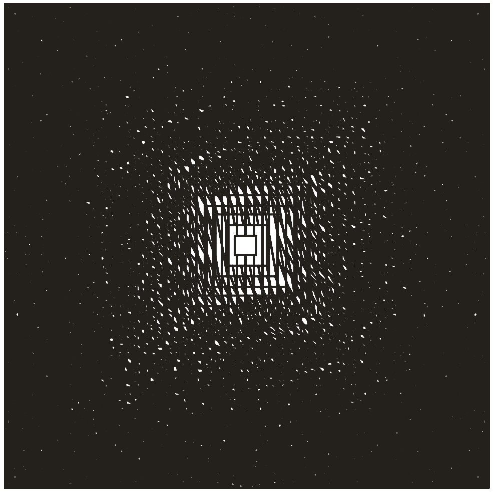
3D Structuring: The „standard“ process



The standard 2½-d process uses a galvo scanner and the 3d-structure is divided into several slices.

Each slice is filled with a pattern of parallel lines.

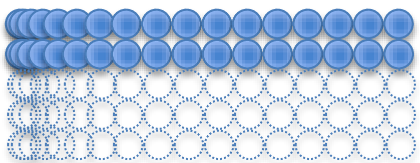
From slice to slice the hatch pattern is turned around a given angle to avoid regular structures at the bottom.



Line start problem

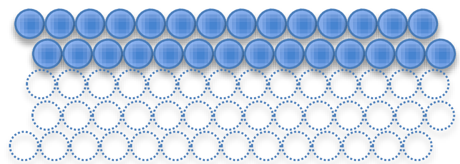
Straight lines have to be generated with mechanical axes, the pulse train is switched on and off via an external modulator

“acceleration” problem



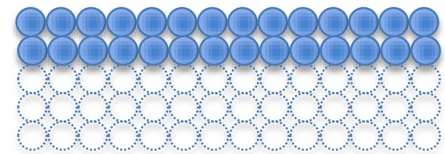
-well defined border
-deep marking at borders

Sky writing

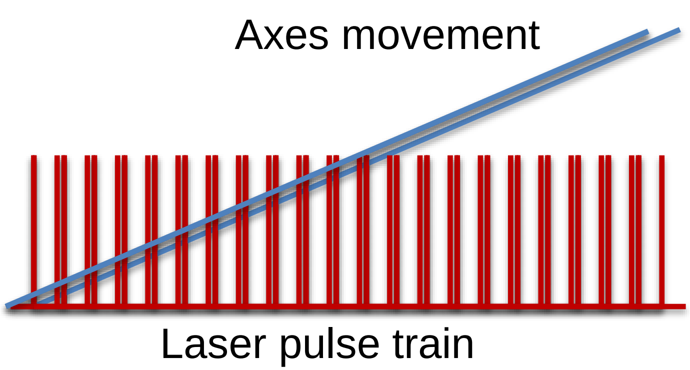


- no deep marking
- diffuse border

Synchronized



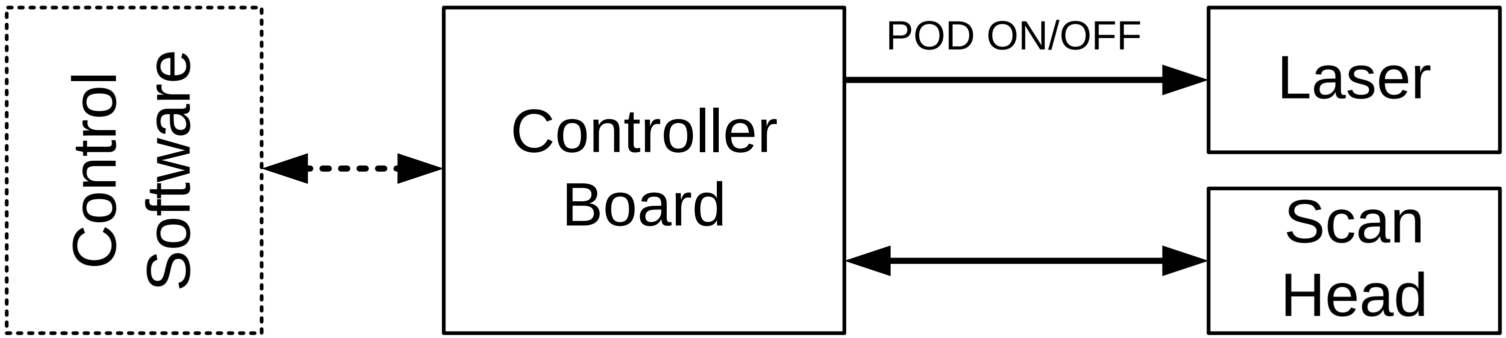
- no deep marking
- well defined border



The first movement defines the location of the starting point
For the next movement you can:
- Shift the pulse train
  Can be done for Q-Switched systems, but is a risky task for standard fs- and ps-systems in MOPA arrangement.
- Tune the axes movement on the pulse train
  needs adapted motion control

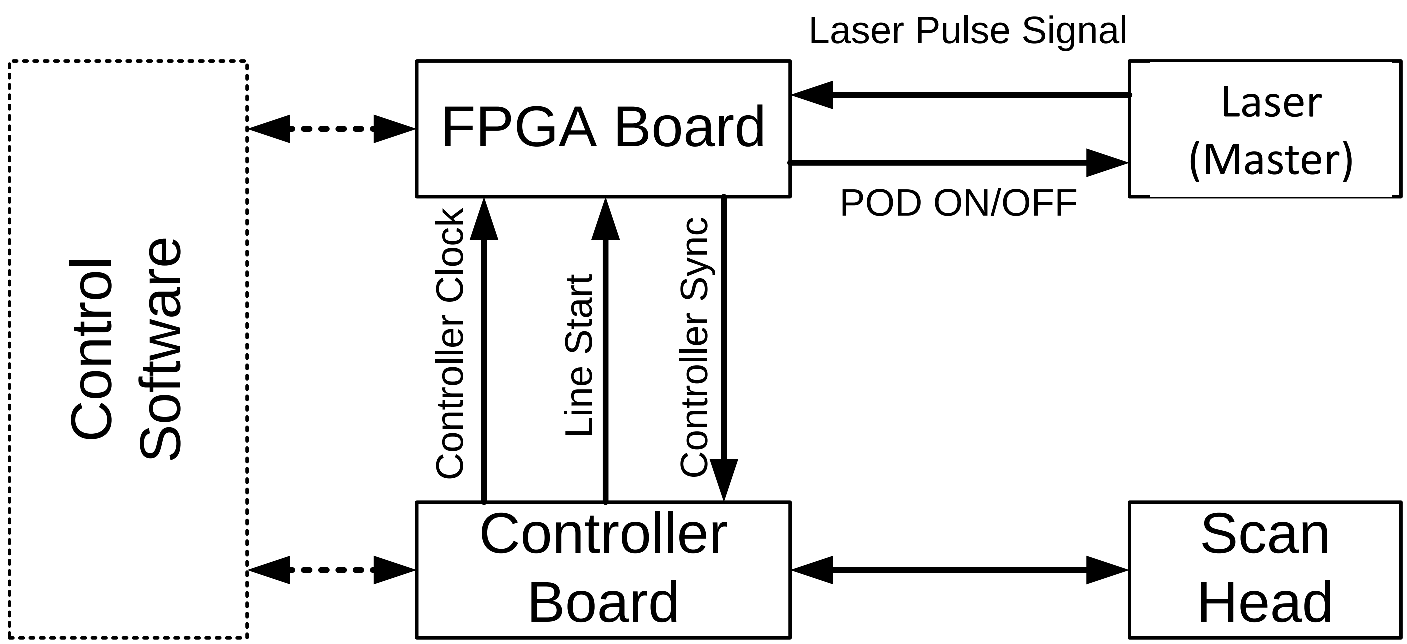
Scanner and Laser Control

Standard laboratory setup with Intelliscan 14, RTC5 and DUETTO ps System:

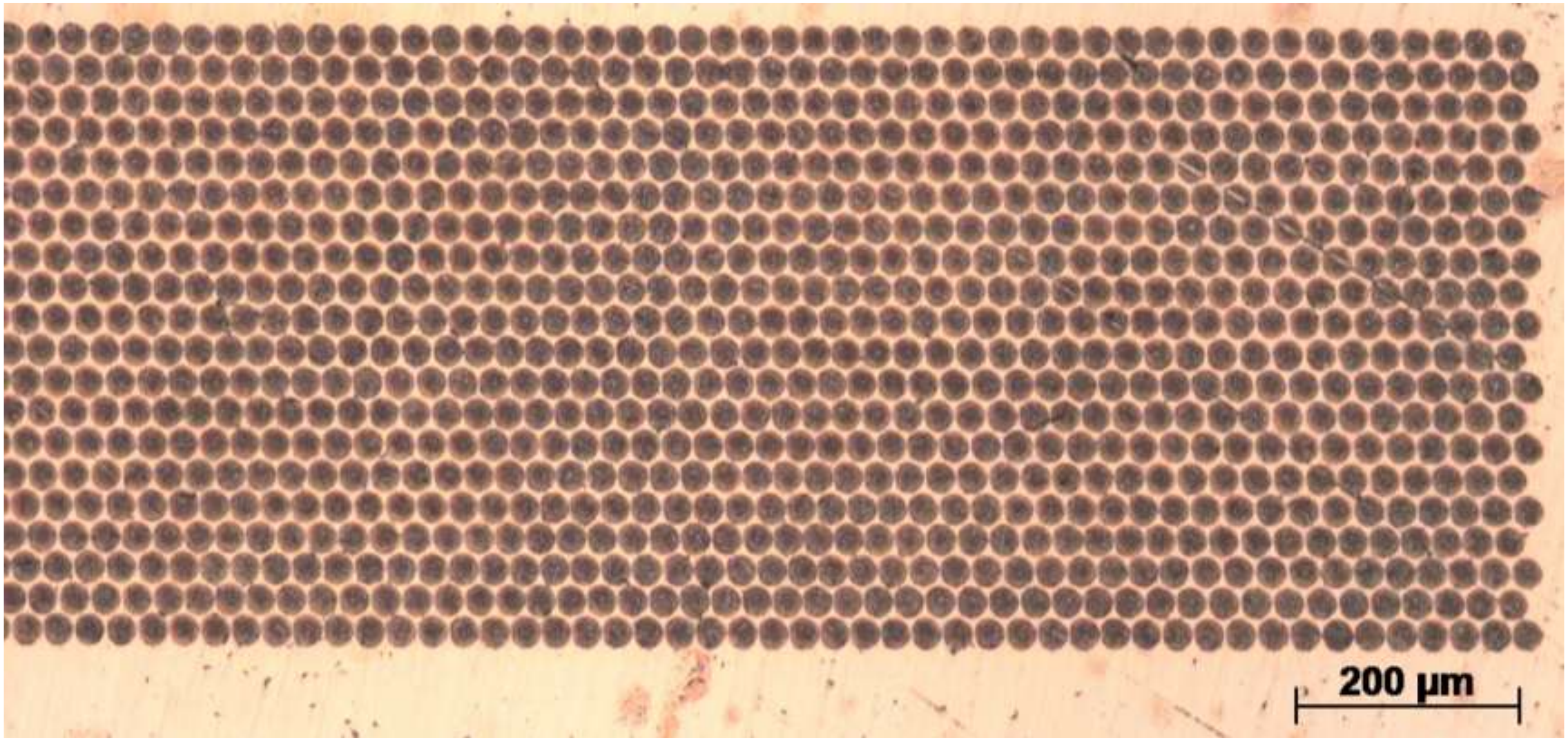


Scanner and Laser Control

Synchronized setup with additional FPGA Board:

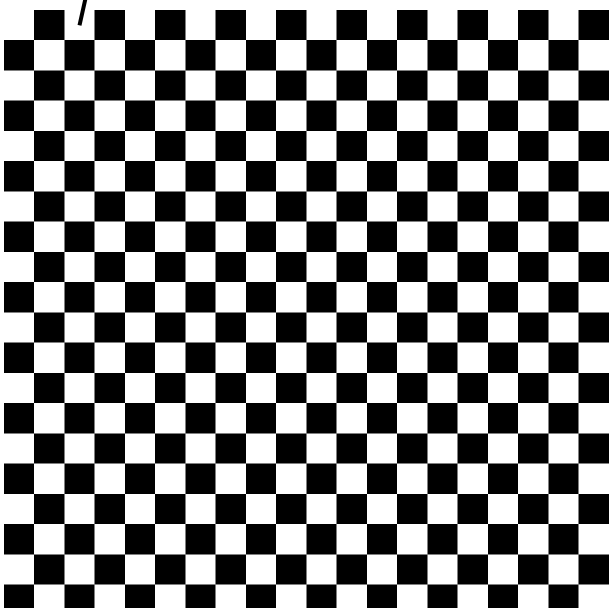


Scanner and Laser Control



Scanner and Laser Control

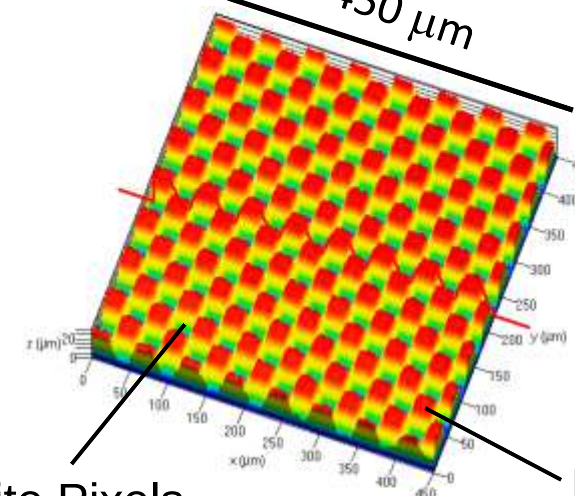
White Pixels = Laser on



Black Pixels = Laser off

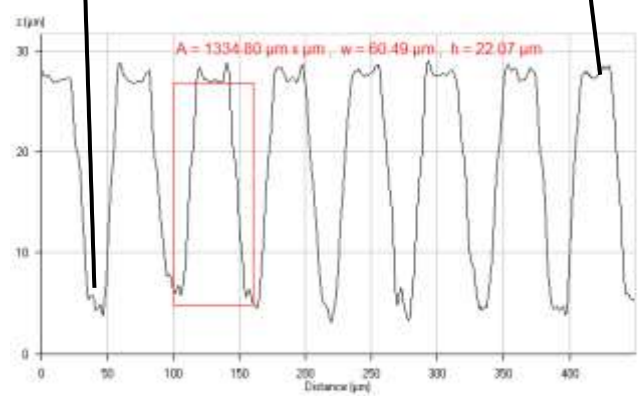
Result:

450 µm



White Pixels

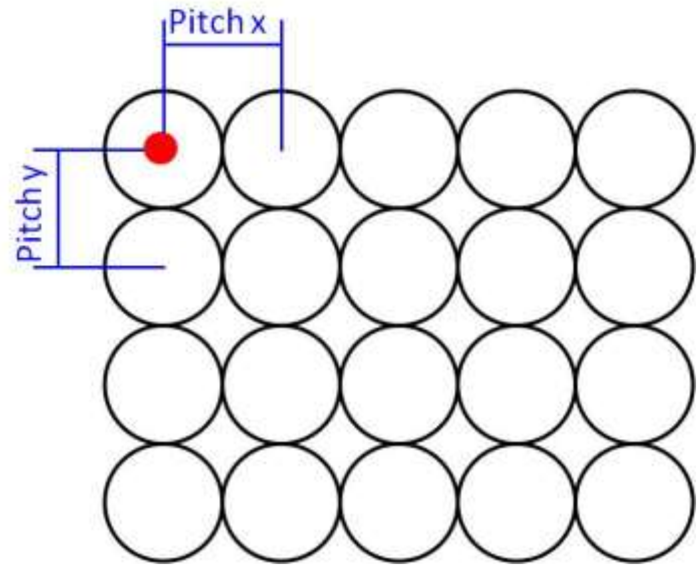
Black Pixels



120 mW, 300 kHz, 3 µm pitch, 100 slices

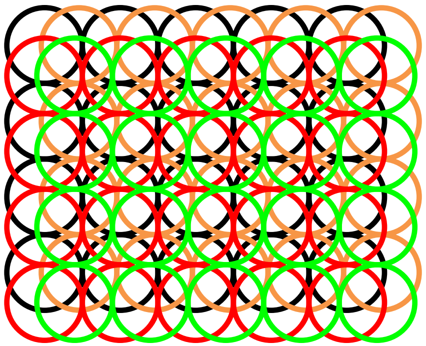
Scan strategy

- Minimal surface roughness
- Best optical effect
- Different strategies

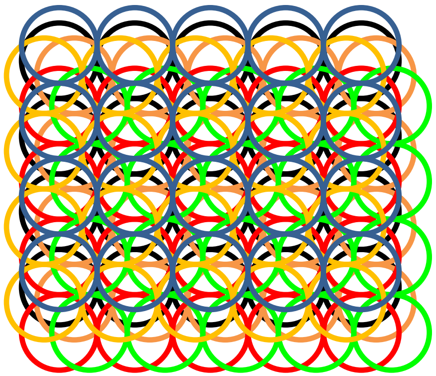


Scan strategy

Fix defined start positions



Random distribution of the start positions

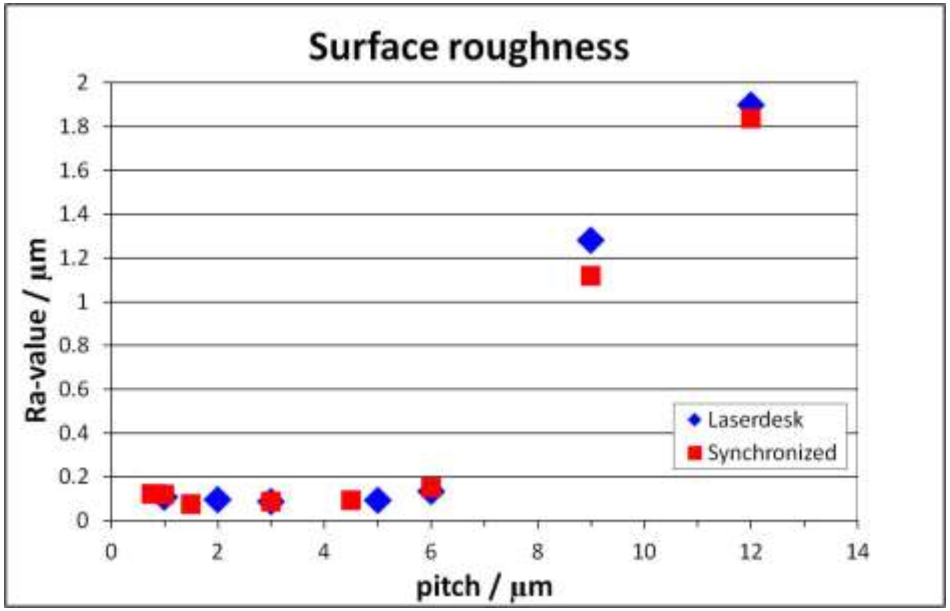


Random distribution

- Uniform random distribution
- Normal random distribution

Best strategy: Start positions determined by a normal random distribution, with $\mu = 0$, $\sigma =$ pitch/4

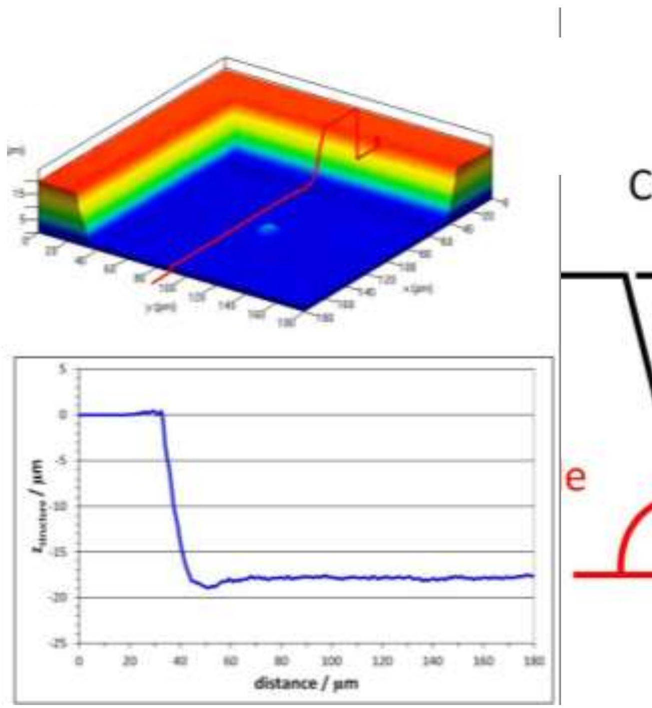
Minimal surface roughness

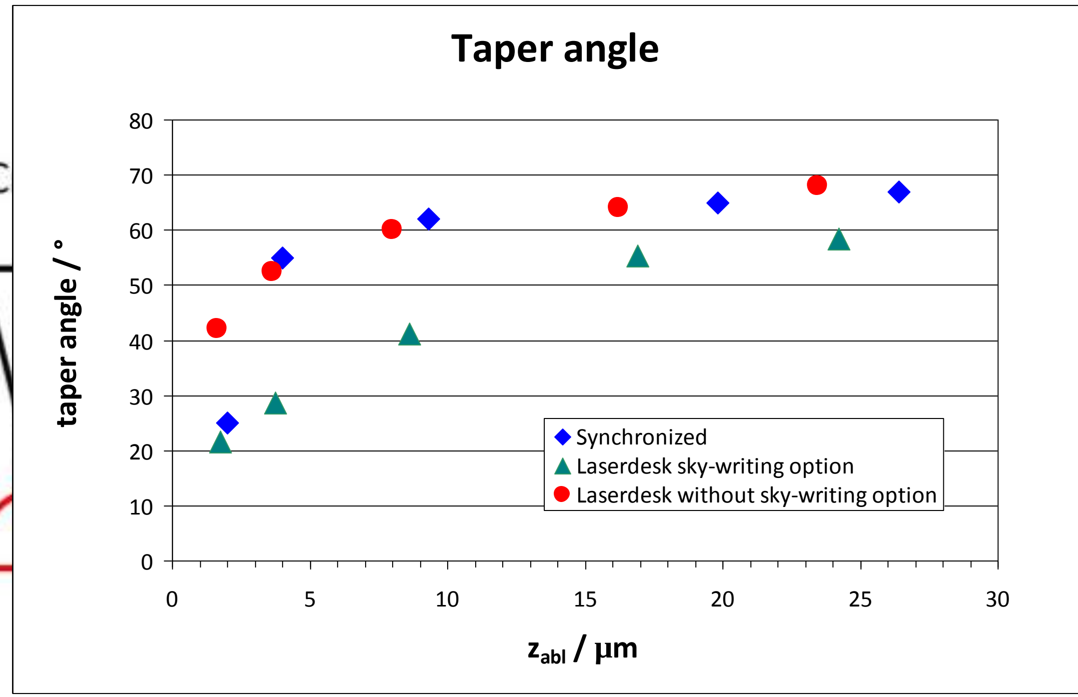


pitch / µm	# slices
1	13
3	120
12	1920

Minimal surface roughness is about 90 nm and produced with a pitch of half of the spot radius.

Steepness of wall / taper angle

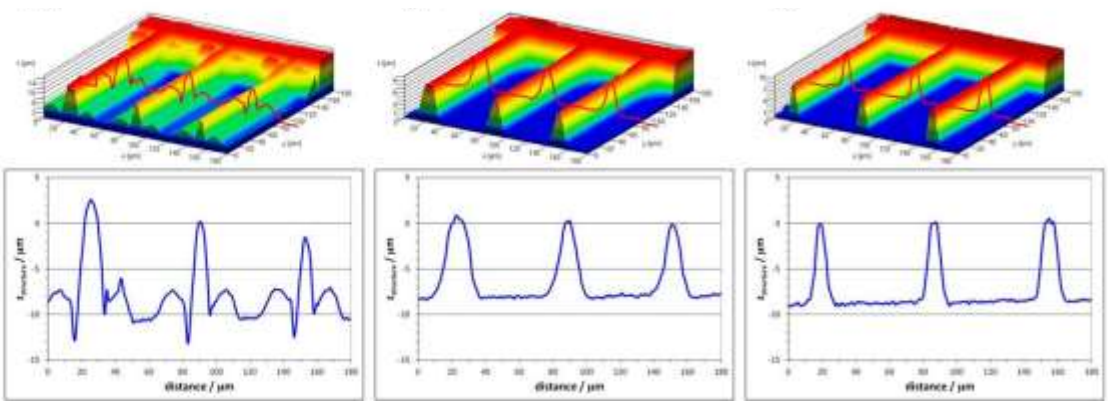




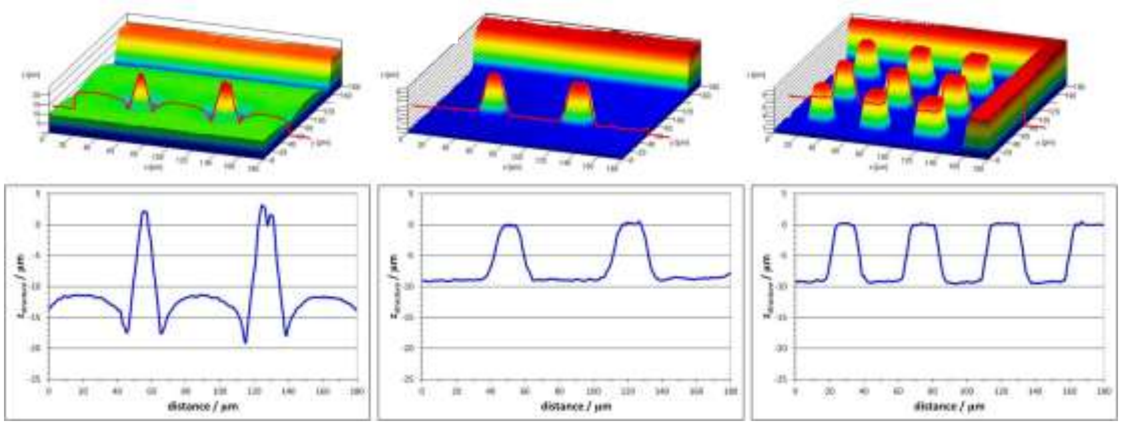
Controlling	Steep taper angle	No deep marks
Laserdesk No Sky-Writing	x	
Laserdesk Sky-Writing		x
Synchronized System	x	x

Minimal structures

Laserdesk Without sky-writing; With sky-writing; Synchronized



120 mW, 300 kHz, 1 μm pitch, 60 slices

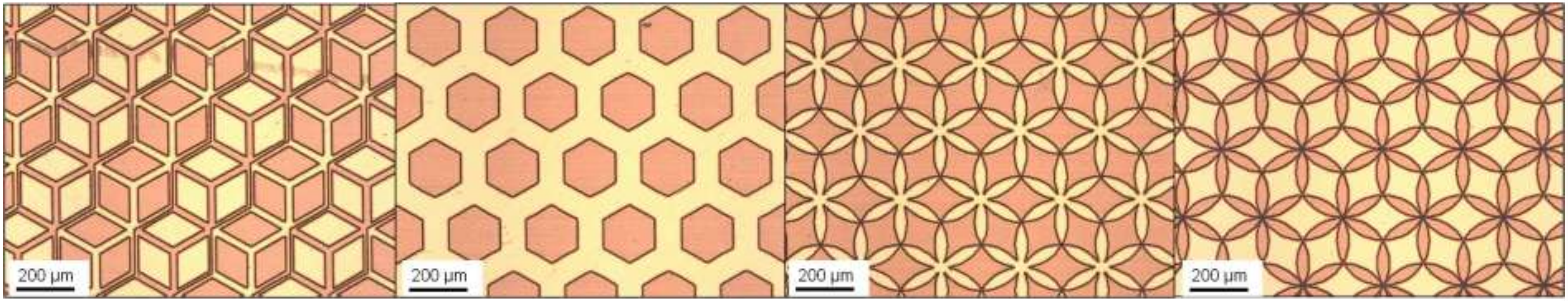


120 mW, 300 kHz, 3 μm pitch, 60 slices

- Minimal web width: 3-5 μm ($\sim w_0/2$)
- Minimal side length: 6 μm ($\sim w_0$)

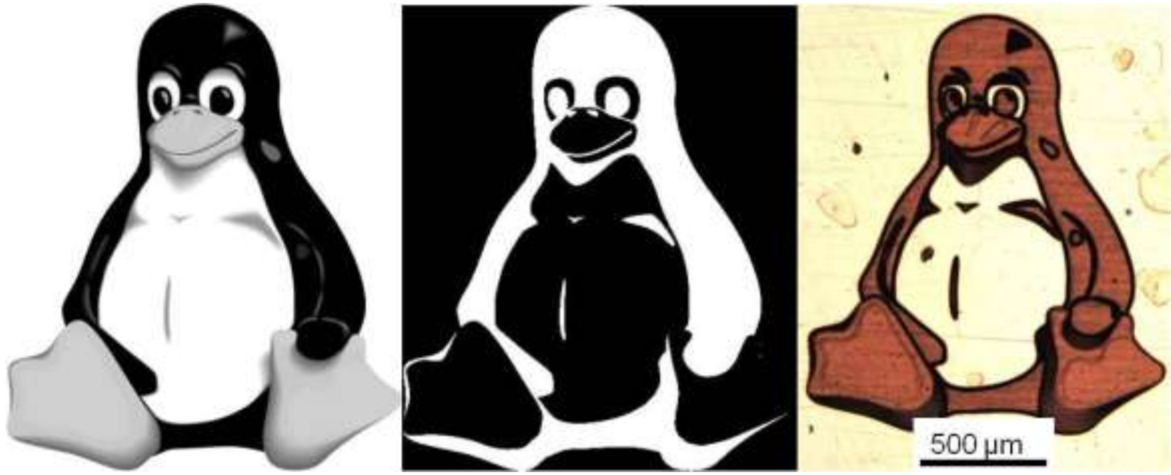
Examples of surface structures in copper

120 mW, 300 kHz, 3 µm pitch, 30 slices

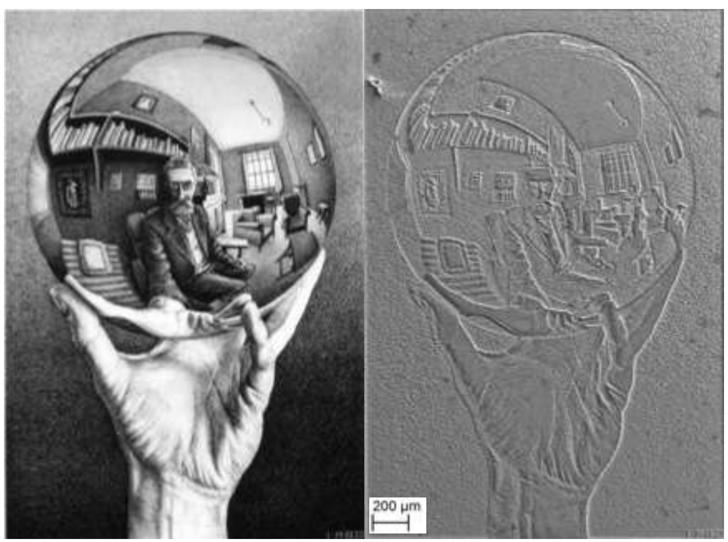


120 mW, 300 kHz, 3 µm pitch, 30 slices

Surface Structuring: Working with gray scale bitmaps

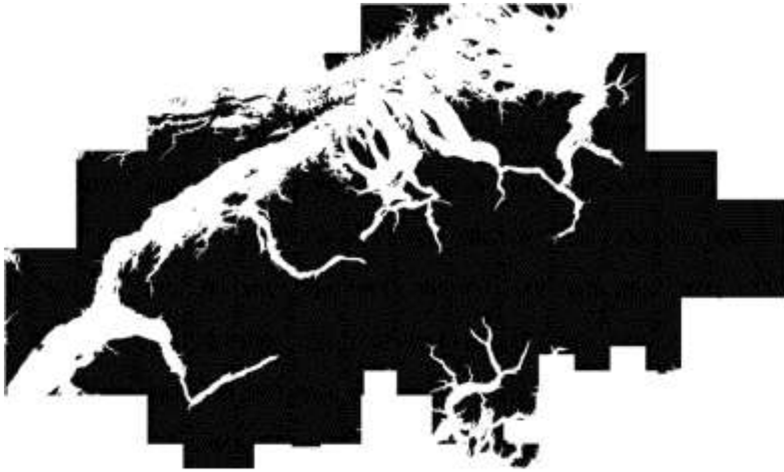


120 mW, 300 kHz, 3 µm pitch, 100 slices

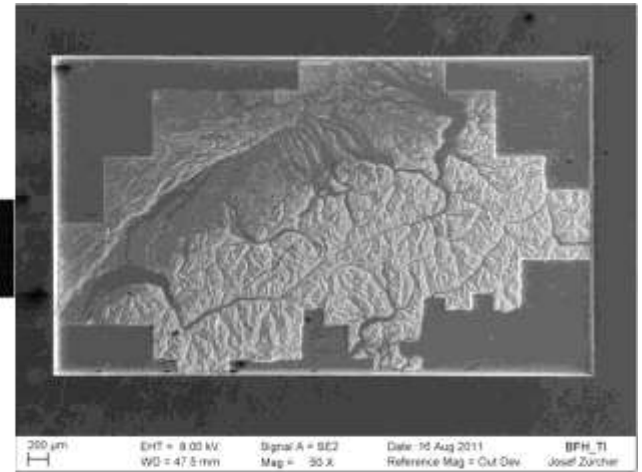


[1]: http://en.wikipedia.org/wiki/File:Tux.svg
[2]: http://brettworks.com/2012/04/26/on-the-musicality-of-m-c-escher/

Surface Structuring: converting 3D data in bitmaps

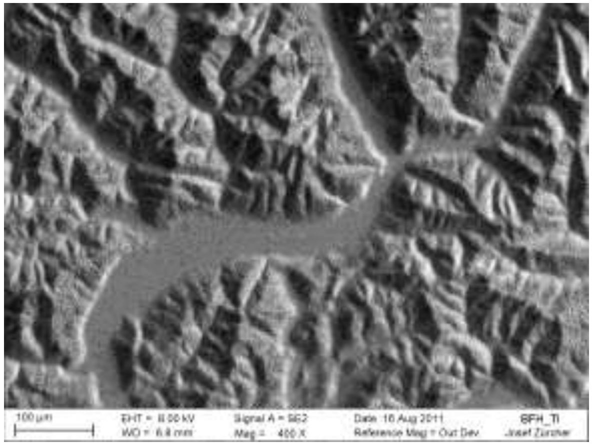


[3]:http://www.swisstopo.admin.ch/internet/swisstopo/de/home.html

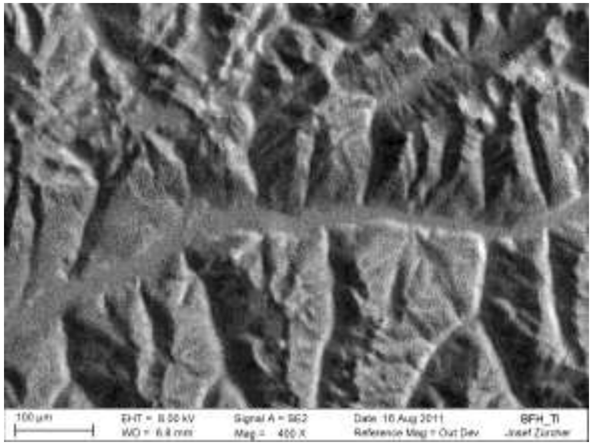


120 mW, 300 kHz, 3 µm pitch, 447 slices

Eiger, Mönch and Jungfrau



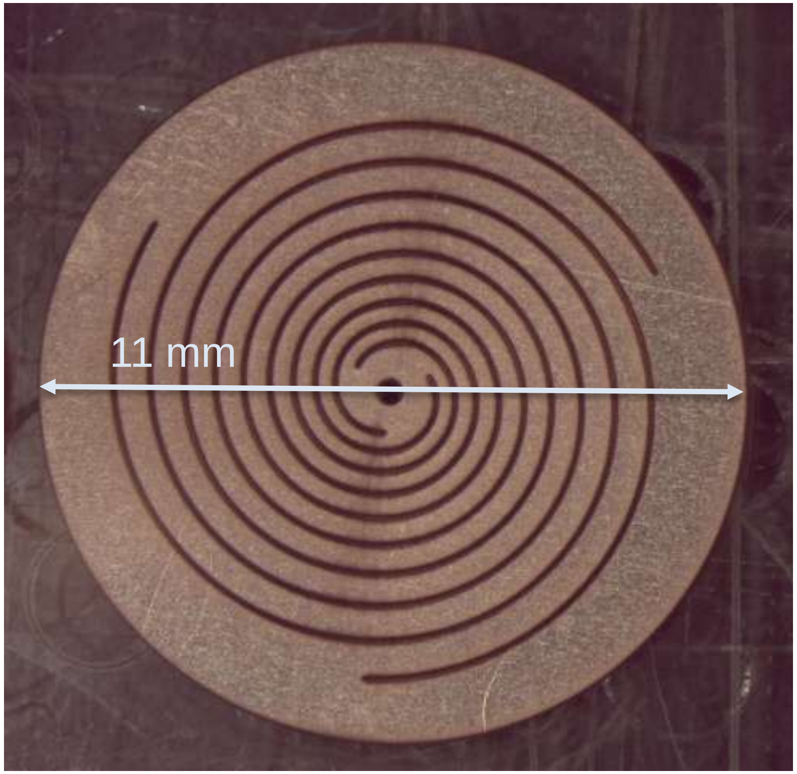
Ticino



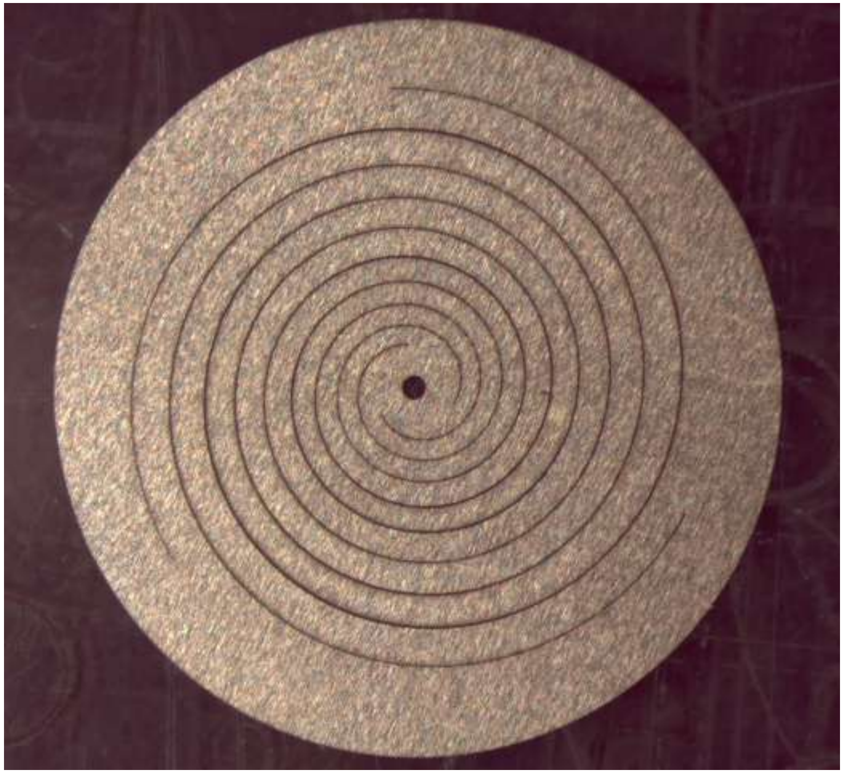
Valais

Cutting of a spiral spring

Front side:



Back side:

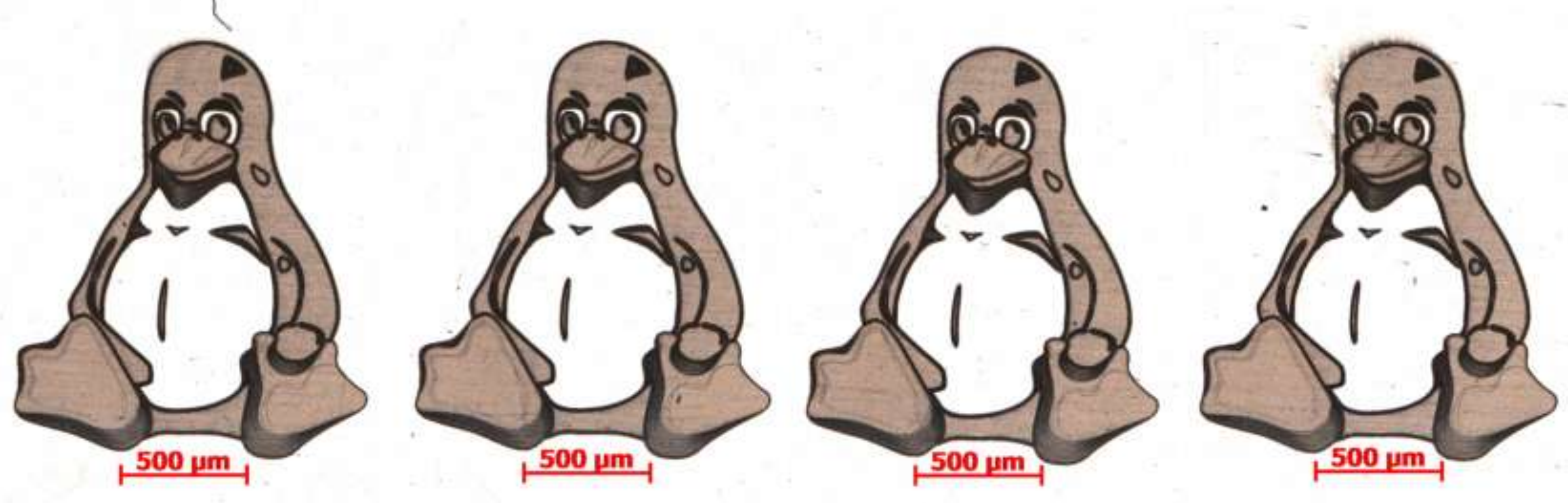


No cleaning

Scaleability

$\lambda = 532\,nm\,;\quad \phi_{th} = 0.11\,J/cm^2\,;\quad \delta = 6.7\,nm\,;\quad f_{obj} = 100\,mm;\quad w_0 = 6.65\,\mu m\,;\quad p = 3\,\mu m\,;$

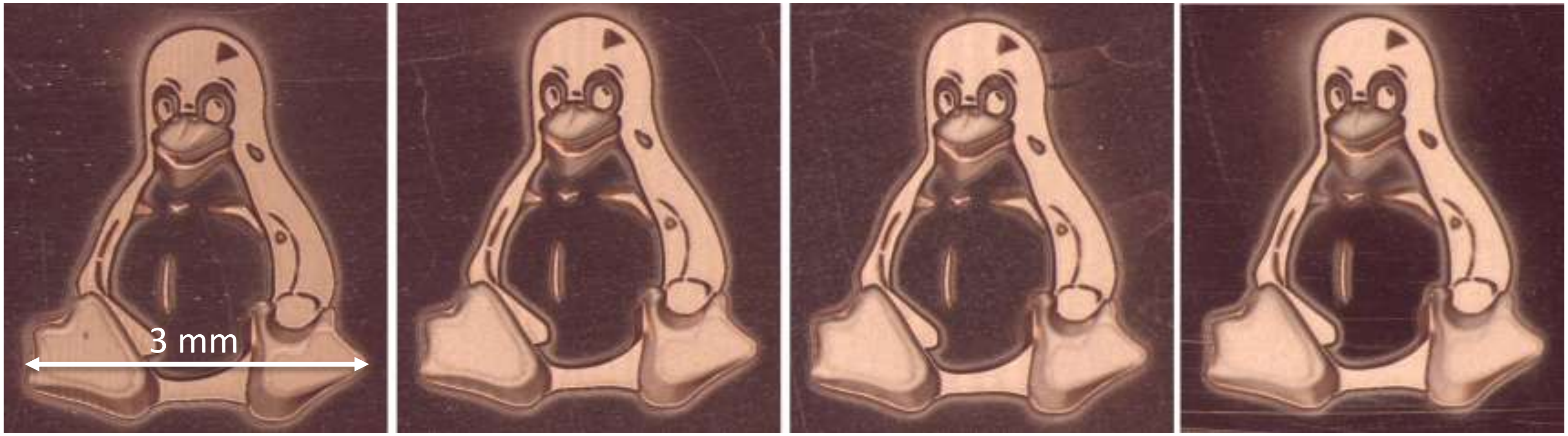
$f_{rep} = 300\,kHz$	$f_{rep} = 500\,kHz$	$f_{rep} = 700\,kHz$	$f_{rep} = 1000\,kHz$
$P_{av} = 120\,mW$	$P_{av} = 204\,mW$	$P_{av} = 285\,mW$	$P_{av} = 409\,mW$
$v = 0.9\,m/s$	$v = 1.5\,m/s$	$v = 2.1\,m/s$	$v = 3.0\,m/s$



Scaleability

$\lambda = 1064\, nm$; $\phi_{th} = 0.3\, J/cm^2$; $\delta = 31.8\, nm$; $f_{obj} = 160\, mm$; $w_0 = 16.3\, \mu m$; $p = 8\, \mu m$;

$f_{rep} = 100\, kHz$	$f_{rep} = 200\, kHz$	$f_{rep} = 300\, kHz$	$f_{rep} = 600\, kHz$
$P_{av} = 925\, mW$	$P_{av} = 1.85\, W$	$P_{av} = 2.76\, mW$	$P_{av} = 5.56\, W$
$v = 0.8\, m/s$	$v = 1.6\, m/s$	$v = 2.4\, m/s$	$v = 4.8\, m/s$



No significant difference is observed -> the process is scalable

Conclusions

For real high precision surface structuring the synchronization of the mechanical axes with the laser pulse train is necessary. This was realized with a standard galvo-scanner and an additional FPGA-board.

The best scan strategy with the synchronized setup was found to be:

- Pitch of about ½* w_0 (3 µm)
- Normal random distributed start positions with μ=0, σ=pitch/4

Results

- Minimal surface roughness of about 90nm
- Steep tape angle and no acceleration marks
- Minimal structure dimensions in the range of ½ to 1*w_0
- Process is scalable