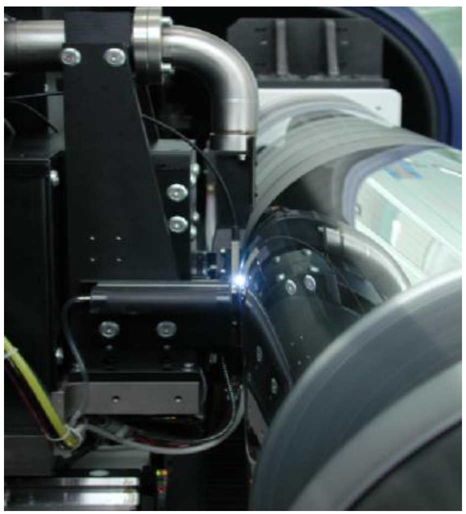
Ultrafast Beam Modulation and delivery for precise 3D laser ablation

- Surface structuring of metals and non-metals for printing tools and embossing dies with ultrafast ps-laser machining systems -

High Resolution 3D – Microstructuring of large areas with ps-Laser



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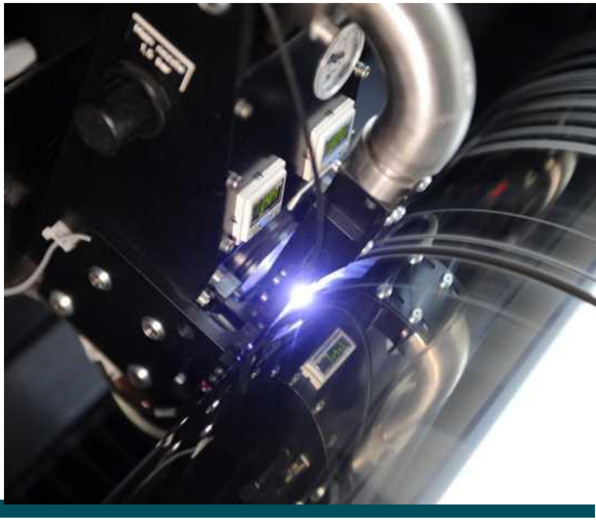
Beat Neuenschwander, Bern University of Applied Science, Switzerland

SLN_ appolo _Workshop, BFH Burgdorf, 04th Nov 2015

SCHEPERS heliograph HOLDING Bern University of Applied Sciences Daetwyler Graphics

Complete solutions for print and embossing industry



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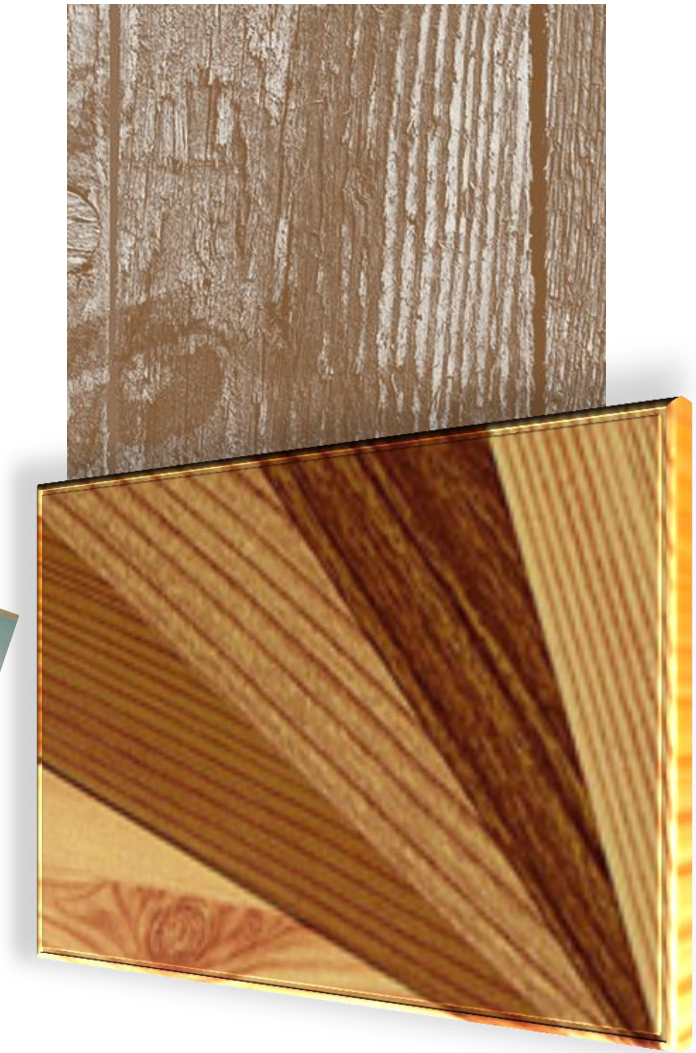
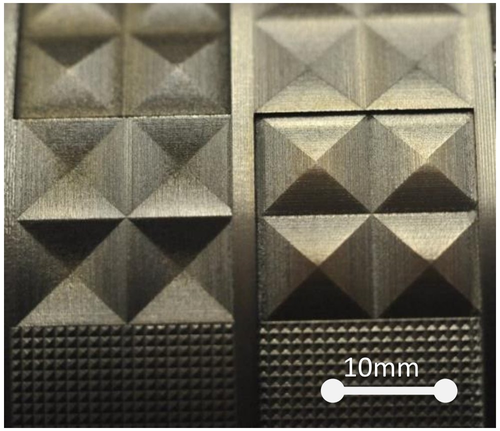
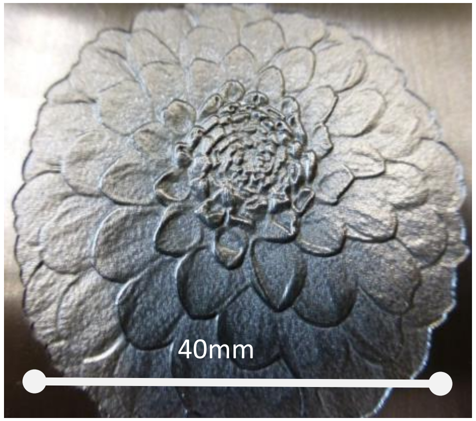
Printing of dayly use articles

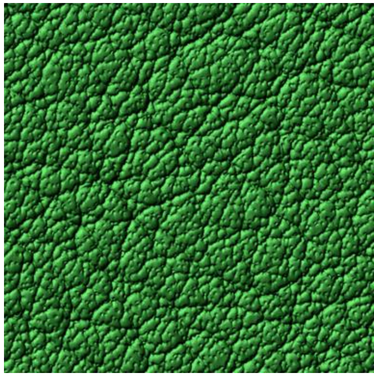
Decor applications

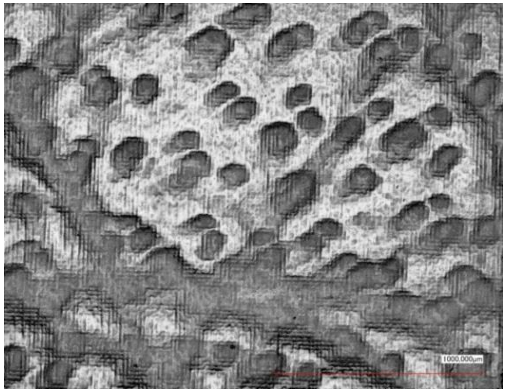


3D-embossing in Steel for decoration

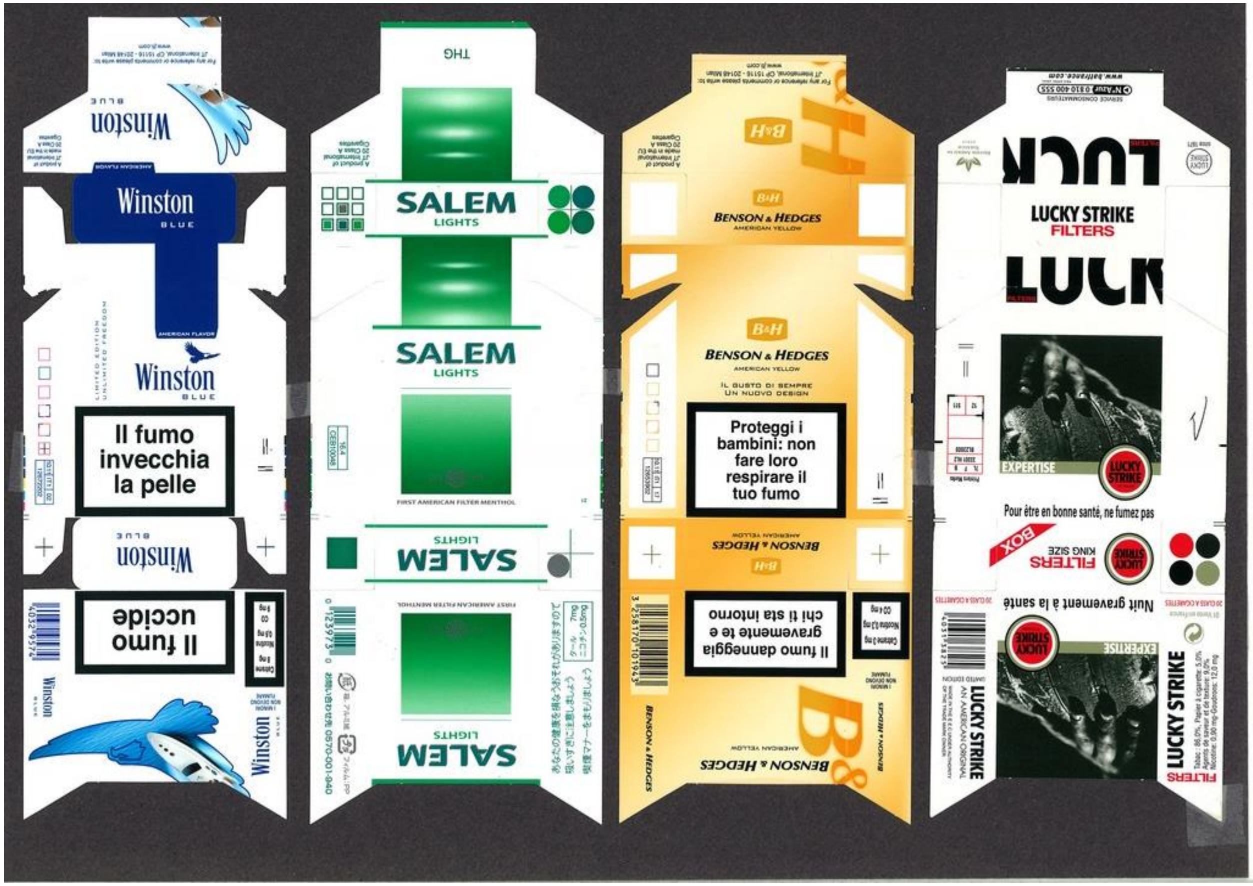








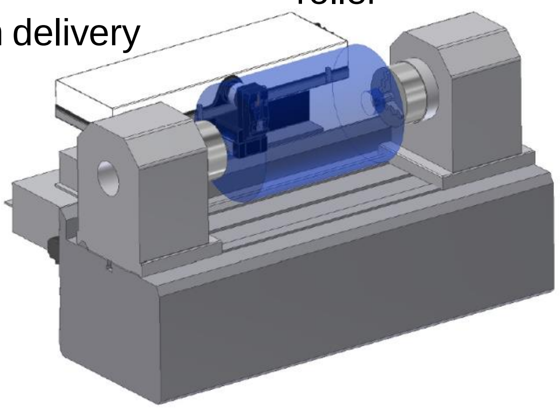
3D-embossing for high value packaging



1. **3D ps laser processing**
   - Screen and layer definition
   - Optimized ablation condition
   - Ablation strategy / overlap / pitch

2. **Applications for printing and embossing**
   - Metallic cylinders for gravure printing / packaging
   - Printed electronics / circuit boards
   - Embossing cylinders for security applications
   - Hot stamping of foils
   - Hybrid materials

Laser engraver

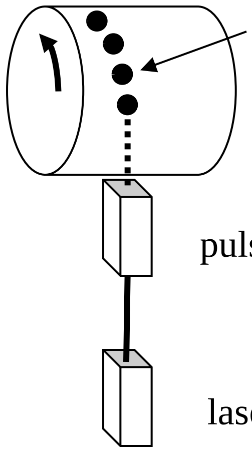


Helical track

rotation speed:
5 – 20 m/s,
max = 30m/s

modulation frequency:
1 – 2 MHz,
max = 8 MHz

laserpower: < 100 W



- 3D surface topographies with depth of 100 nm to 1 mm, area range 0.01 to 7 m^2

→ high resolution 3D microstructuring of small and large areas with pulsed lasers

1. Laser structuring of roller surfaces

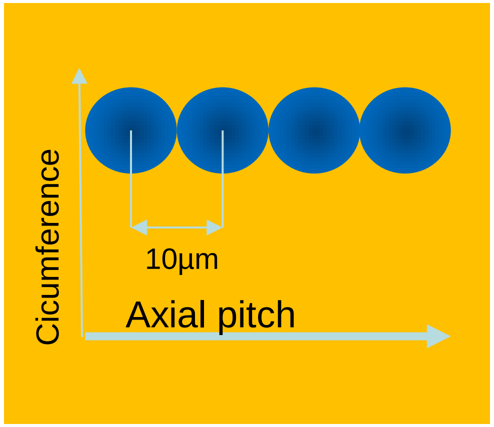
Embossing cylinder

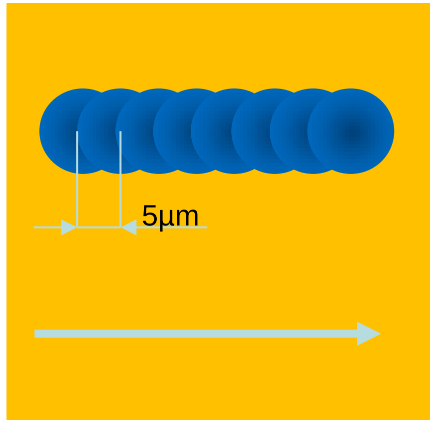
Cylinder surface coating structure

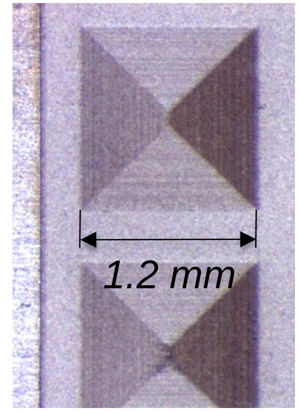
engraving in Cu layer, Steel

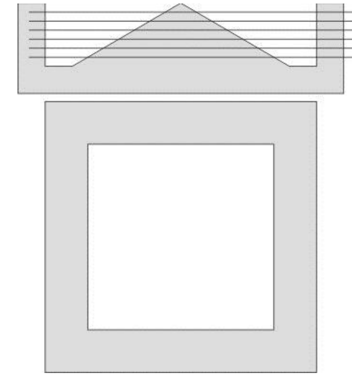
or directly in a (thick) Cr layer for highest reproducability

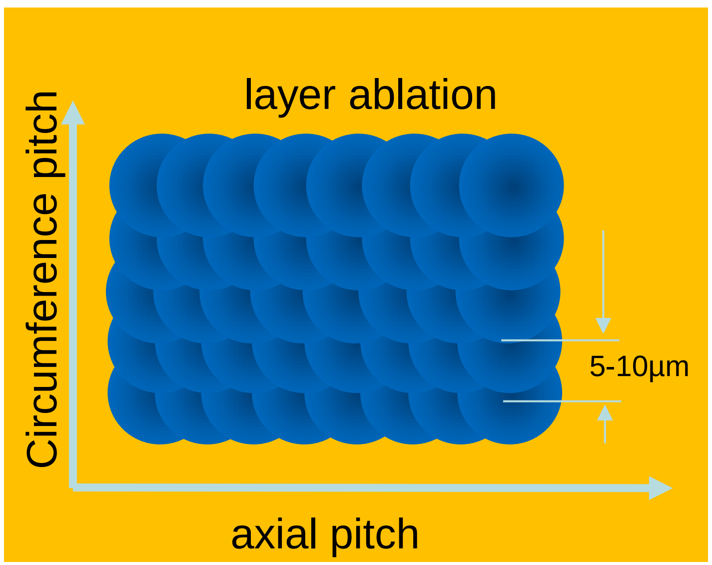
1.1 Layer by layer ablation











pitch → depth/layer and roughness

3D Data

Grey-tone	# Layer	Depth
1%	1	100 nm
2%	2	
3%	3	
4%	4	
5%	5	
6%	6	
.	.	
.	.	
100%	100	10µm

How to get a maximum of ablated volume with a certain amount of total laser energy**?**

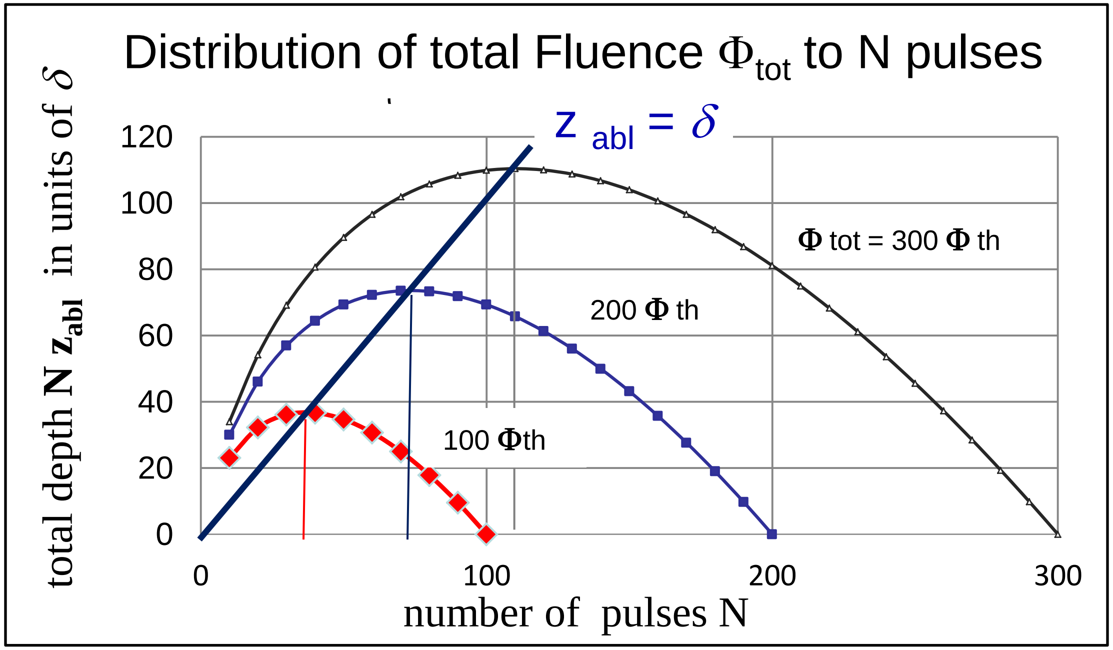
What is the best distribution of total energy (or total fluence Φ_{tot}) to N pulses**?**

$$z_{abl} = \delta \cdot \ln(\Phi / \Phi th)$$

δ = energy penetration depth [1]

→ max. ablation efficiency and max. **total depth = N z_{abl}**, if for a single pulse:

$z_{abl} = \delta$ → $\Phi_{opt} = e \cdot \Phi th$ (Tophat beam)



→ Best repetition rate for maximum of ablated volumen/min

[1] C. Momma, S. Nolte, B. N. Chichkov, F. v. Alvensleben, A. Tünnermann, "Precise laser ablation with ultrashort pulses", Appl. Surf. Sci., 109/110, 15 – 19 (1997)

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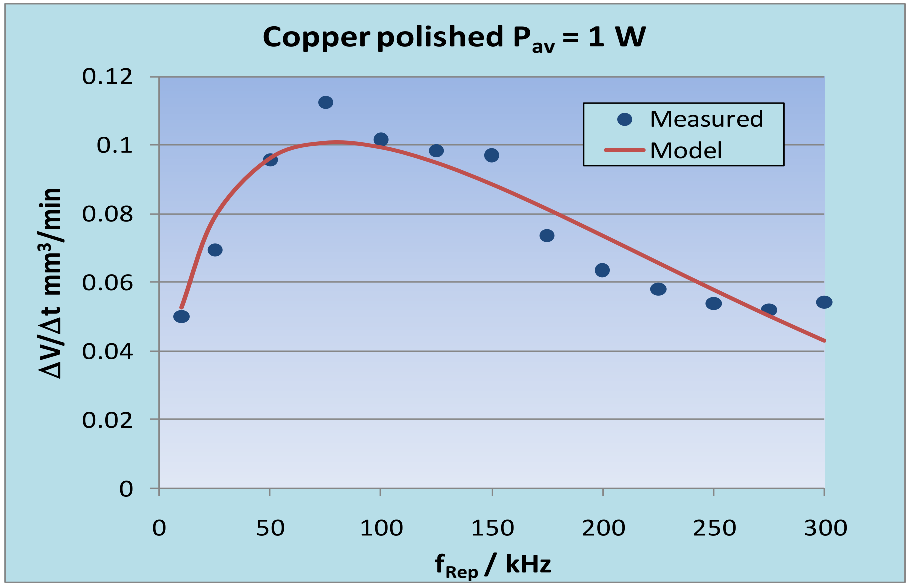
What is the best distribution of total energy (or total fluence Φ_{tot}) to N pulses**?**

$$z_{abl} = \delta \cdot \ln(\Phi / \Phi th)$$ δ = energy penetration depth [1]

→ max. ablation efficiency and max. **total depth = N z_{abl}**, if for a single pulse:

$z_{abl} = 2\delta$ → $\Phi opt = e^2 \cdot \Phi th$ (Gaussian beam) [2]

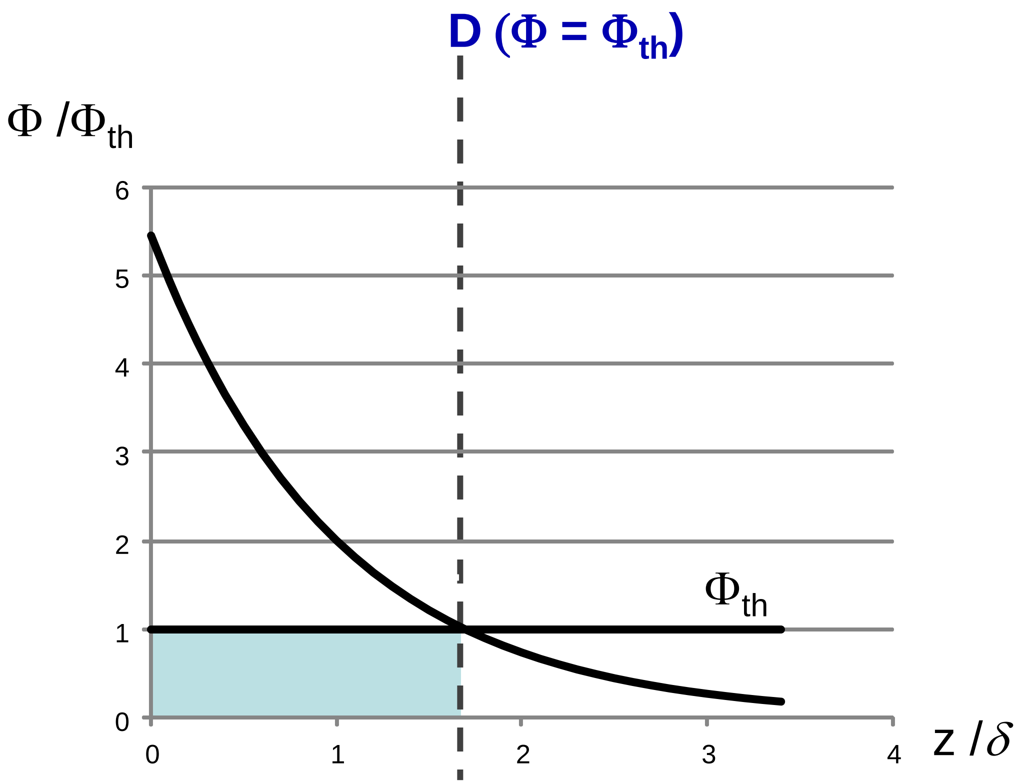


Best repetition rate for maximum ablated volumen/min at Cu

[2] B. Neuenschwander, G. Bucher, G. Hennig, Ch. Nussbaum, B. Joss, M. Muralt, S. Zehnder, U. Hunziker, P. Schuetz, „Processing of dielectric materials and metals with ps-laserpulses“, Proc. of ICALEO, M101 (2010)

Simplified model (in case of Tophat beam profile, not including nonlinear effects)

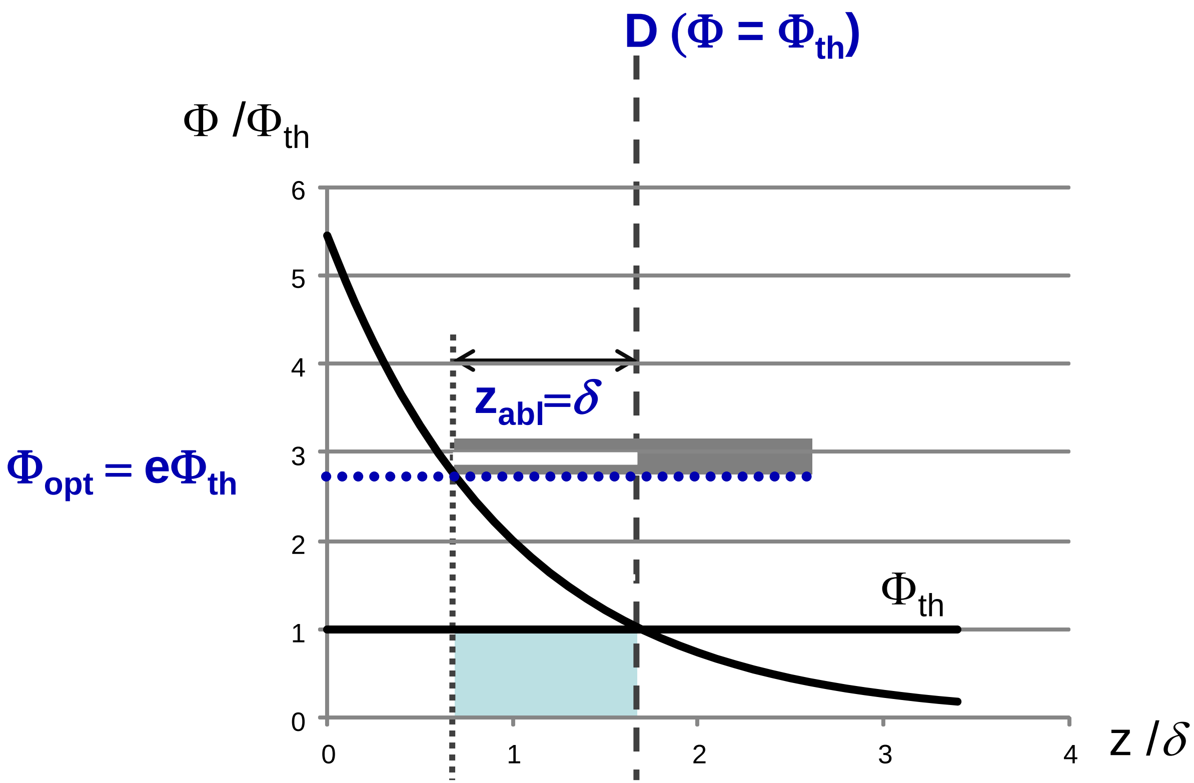
$$\Phi(z) = \Phi(0) \cdot e^{-z/\delta}$$



- Fluence penetrating the material deeper than **D ($\Phi = \Phi_{th}$)** is lost → heating
- Fluence above treshold fluence is more as is necessary for ablation and also lost
- The used part of fluence is marked in blue.

Simplified model (in case of Tophat beam profile, not including nonlinear effects)

$$\Phi(z) = \Phi(0) \cdot e^{-z/\delta}$$



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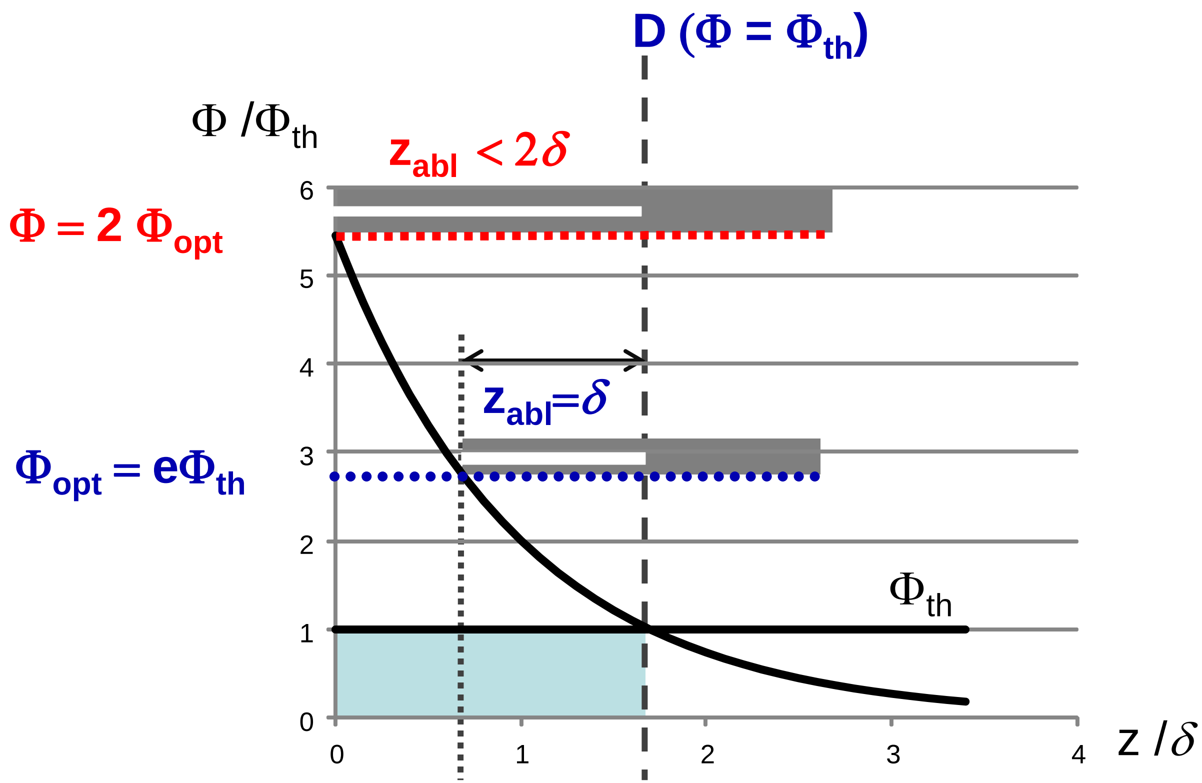

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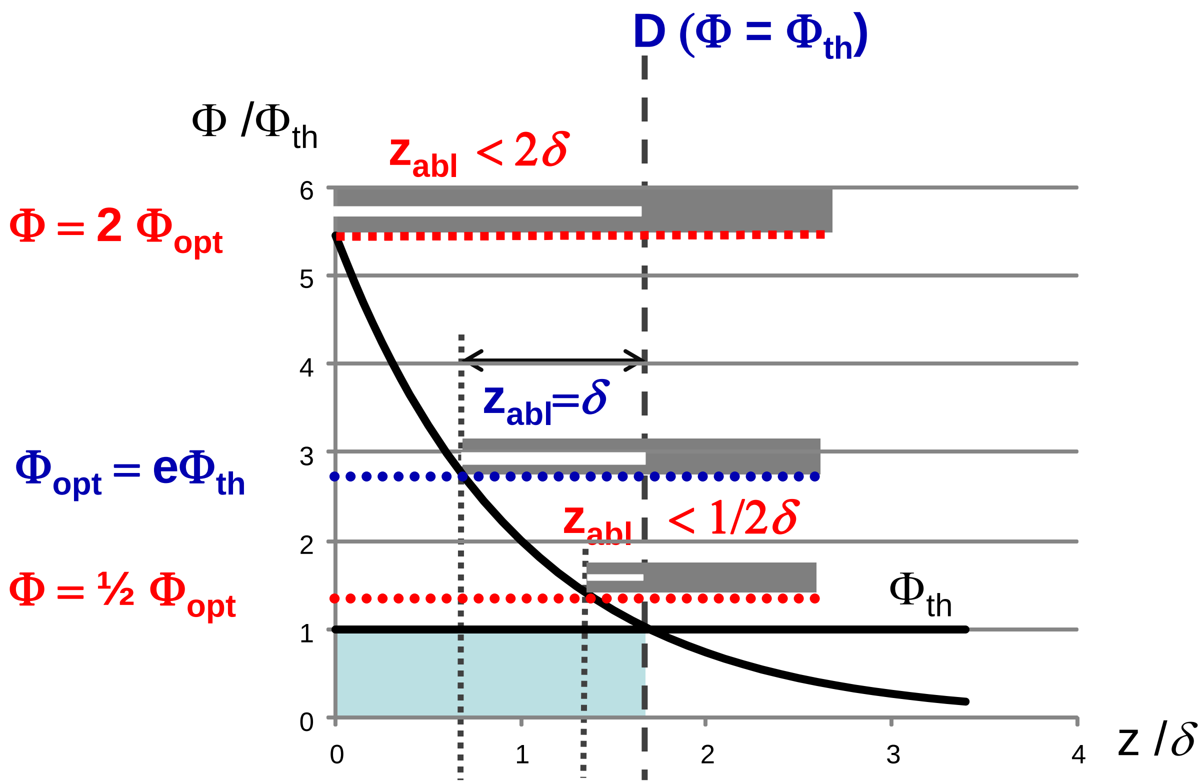


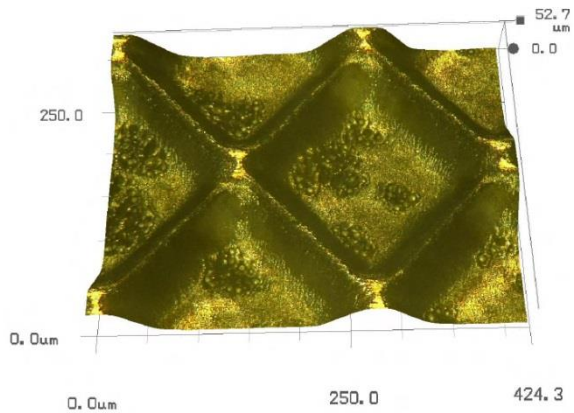
- Fluence penetrating the material deeper than **D ($\Phi = \Phi_{th}$)** is lost → heating
- Fluence above treshold fluence is more as is necessary for ablation and also lost
- The used part of fluence is marked in blue.

$\Phi = \Phi_{opt}$ → $z_{abl} = \delta$; **best ratio (used fluence/ lost fluence) of a pulse, best efficiency**

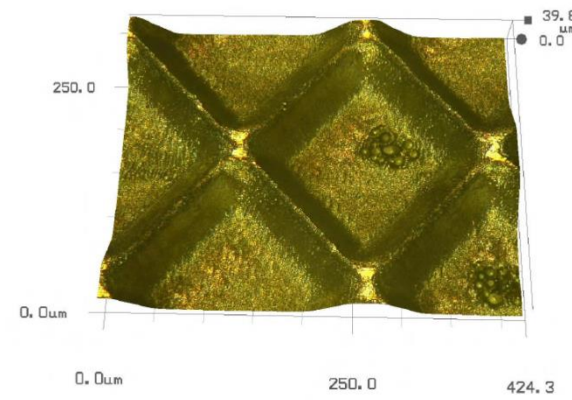
High intensity single pulses → cavities, dots and CLP's

Laser parameters:

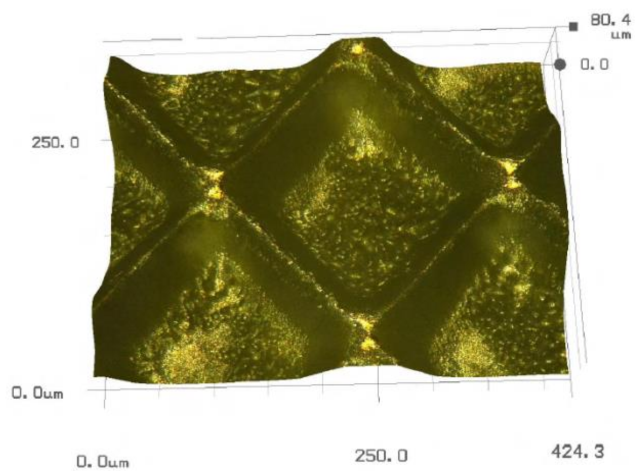
Pulse length 10 ps
power 20 W
Rep.-Rate: 2 MHz
Focus size 10 µm
Fluence: 13 J/cm²



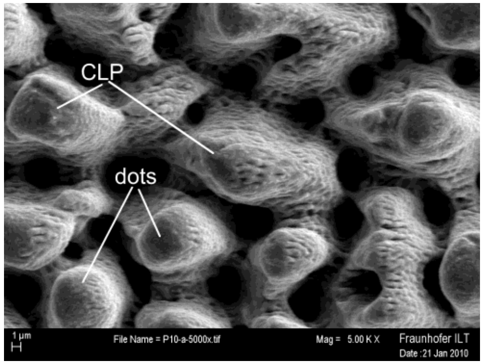
Scan speed 18m/s

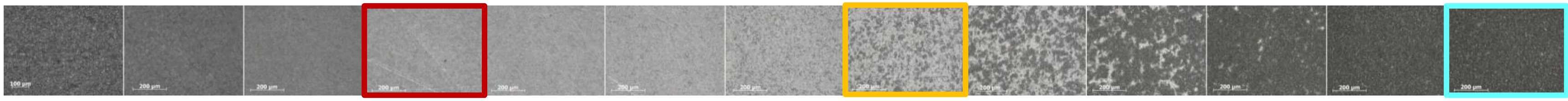


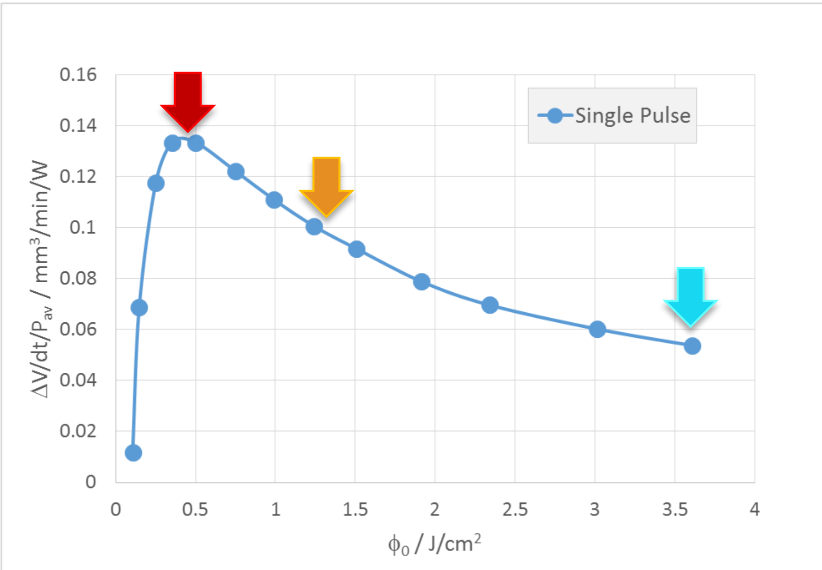
Scan speed 15m/s



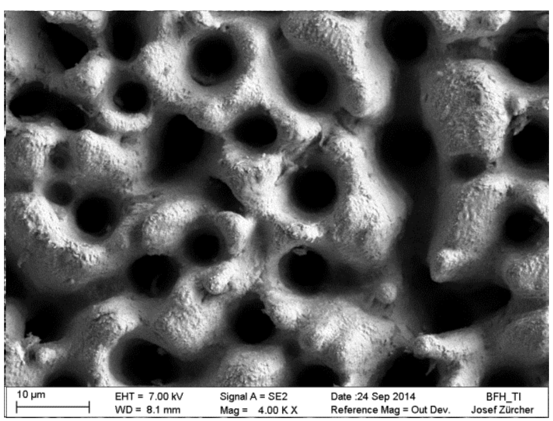
Scan speed 12m/s

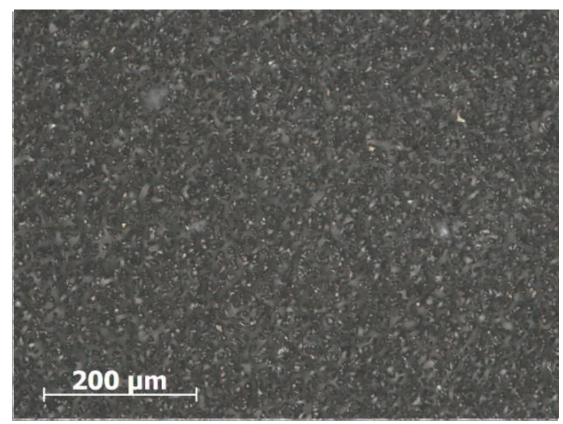






- f_r = 200kHz, w_0 = 16 µm
- High surface quality near optimum point
- Formation of cavities starts for energies of about $2E_{opt}$
- For higher energies the area becomes fully covered by cavities

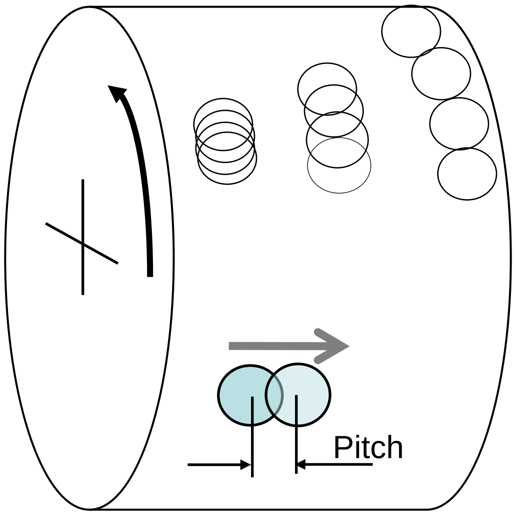




How to apply a power of e.g. 50 W by ps laser while keeping optimum pulse fluence?
→ How to distribute the pulses spatially and timely?
(scan algorithm, beam movement or parallel processing)

Pulse pitch/diameter 25% 50% 100%

pulse length:	10 ps
spot diameter:	10 µm
repetition rate:	2 MHz
mean power(opt):	**0.5 W**



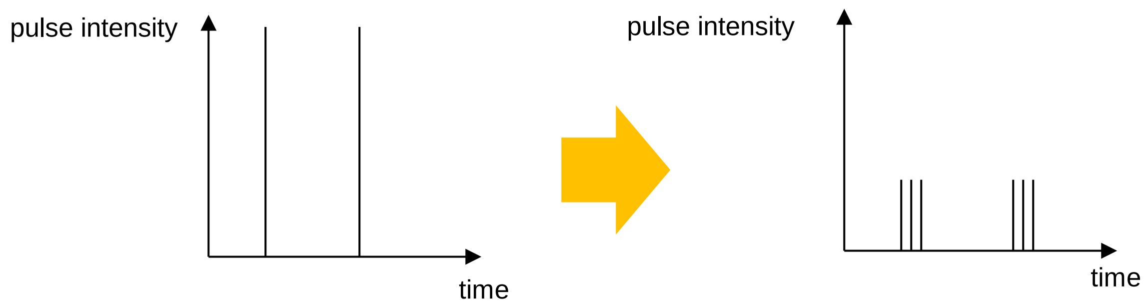
→effective # of pulses at same position = 1 – 16 per layer

Rotation Speed 5m/s 10m/s 20m/s < limit 30m/s

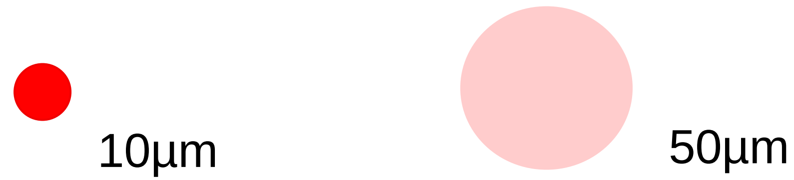
Efficient operation at optimum fluence per pulse with high power ps laser

1. High repetition rate and high scan speed

2. Puls-Bursts

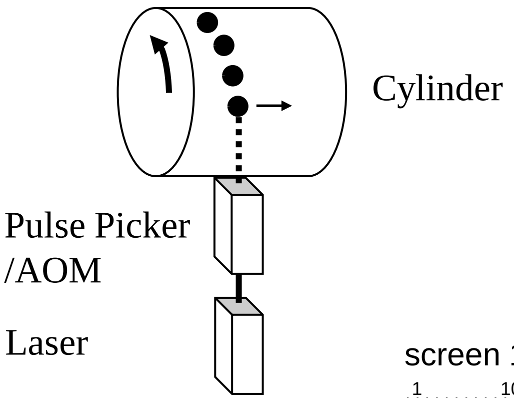


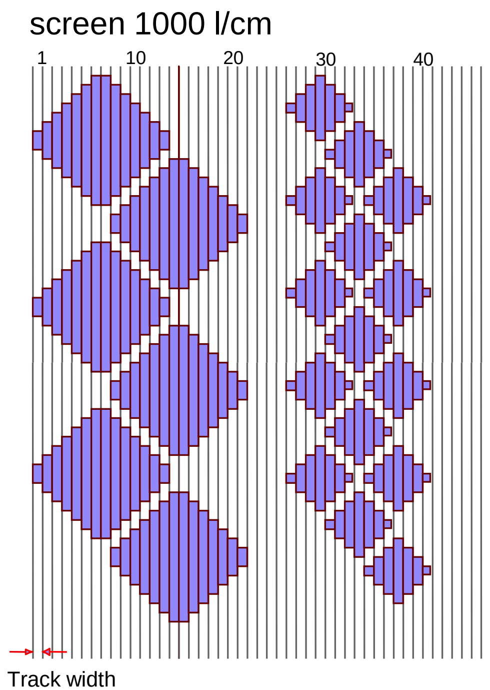
3. Larger spot diameter



4. Distribution of power to Multibeam arrangements (beam splitter/DOE)

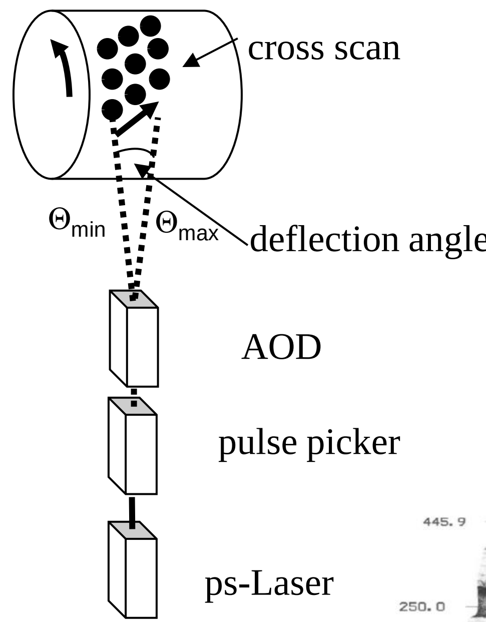
Rotation speed of the roller: < 30 m/s

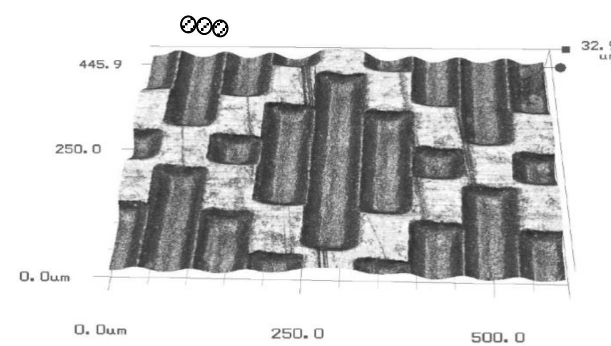




Imagesetter
Process

Additional Crosscan:
15 -150 m/s for a screen 1000–100 l/cm
typical scanangle < 10 mrad





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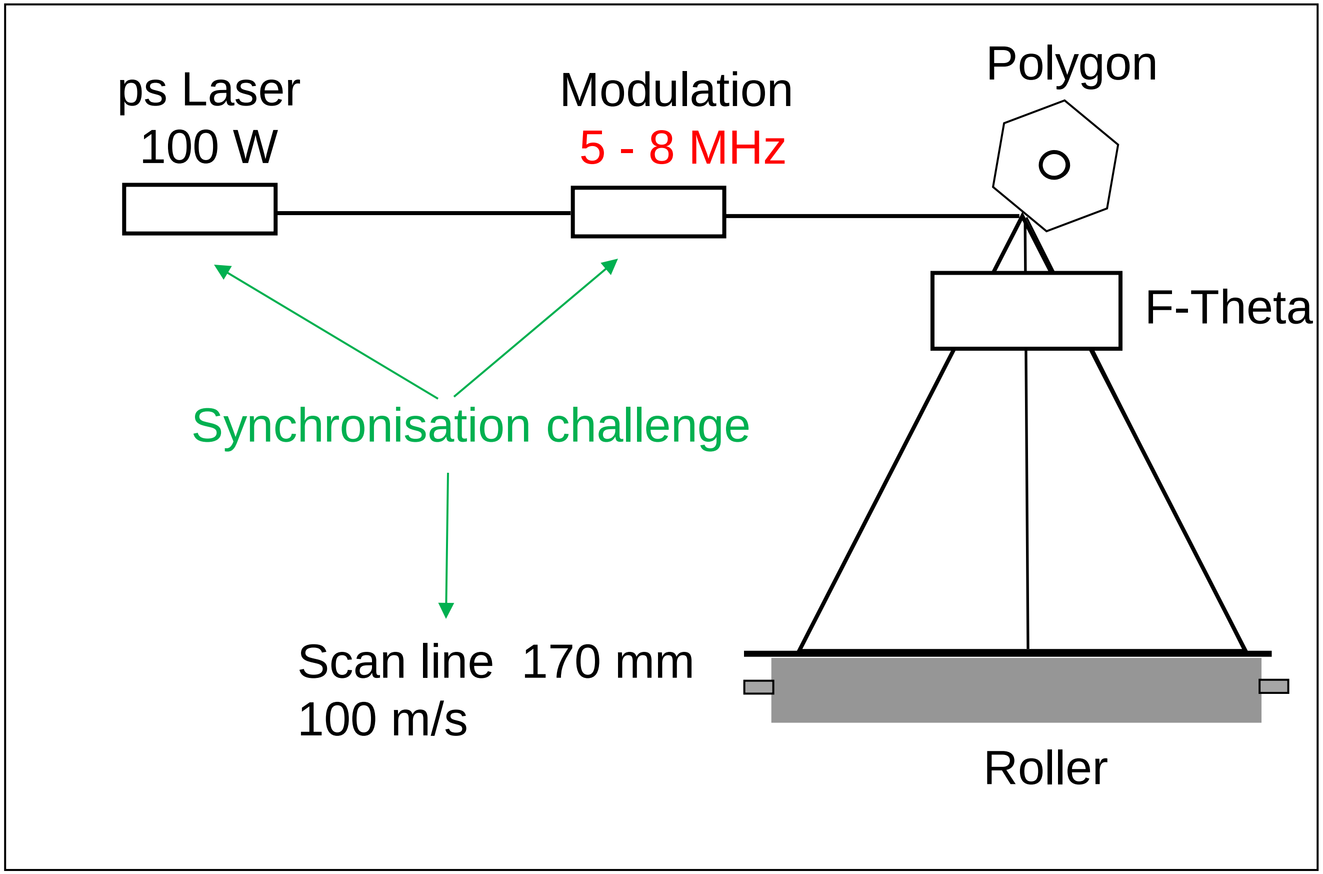
ps Laser
100 W
Modulation
5 - 8 MHz
Polygon
F-Theta
Synchronisation challenge
Scan line 170 mm
100 m/s
Roller

1.7 Appolo Consortium

COOPERATION

appolo

http://appolo-fp7.eu/

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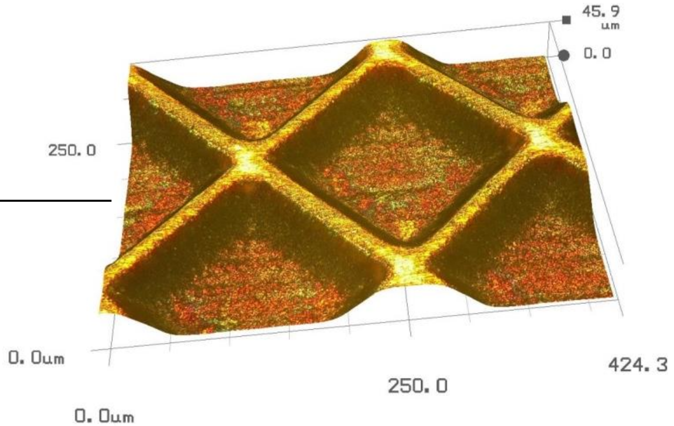
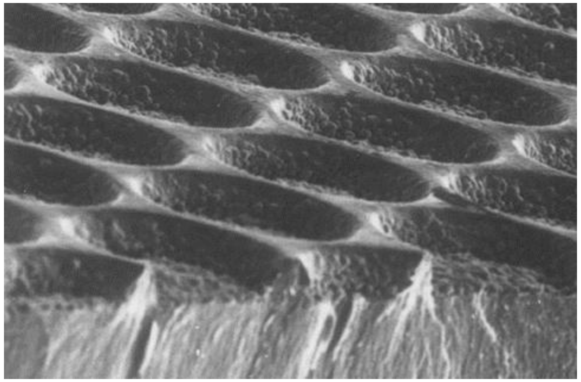
Gravure cells **(80 l/cm)**

ps-laser	10 ps, 40W, 2MHz
spotsize	20 µm
pitch	5 µm // 2000 l/cm
depth	1 µm / layer
# layer	25
scan speed	10 m/s
time	1333 min/m² /layer
	555 h/m² in total

ns- laser	120 ns, 600 kHz, 200W
spot size	20 µm
pitch	10 µm // 1000 l/cm
depth/layer	25 µm
time	280 min/m² →**4,7h/m²**

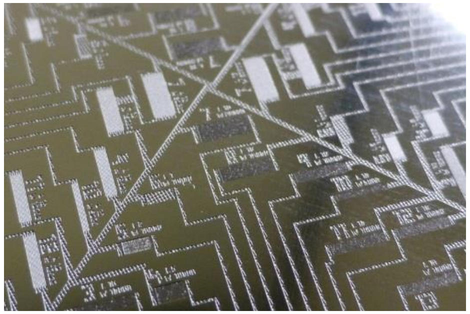
µs-laser	1000 ns, 100kHz, 500W
pitch	125 µm // 80 l/cm
time	**11 min/m²** 1 shot → 1 cell

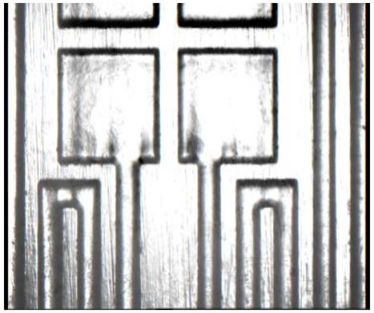




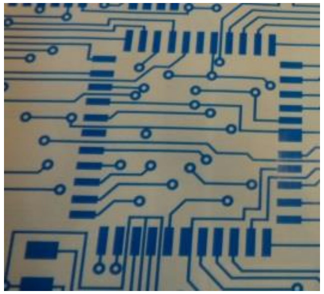
Chromium printing form

cell geometry depends on ink viscosities



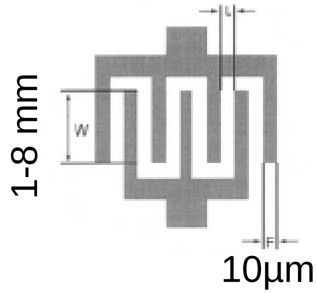


Antenna, circuit wires

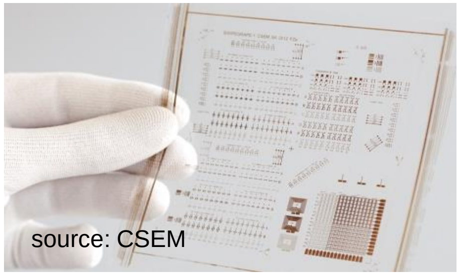


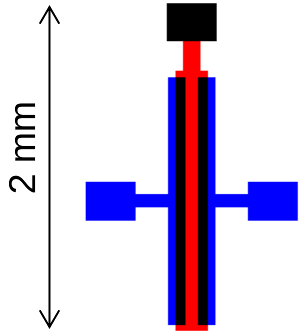
Organic Thin Film Transistor OTFT

source and drain contacts

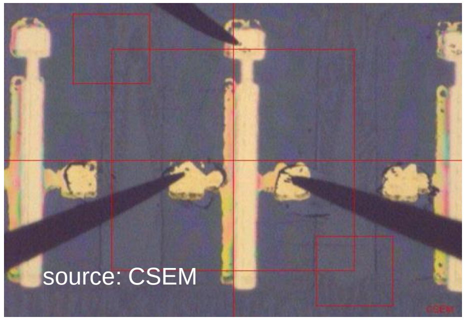


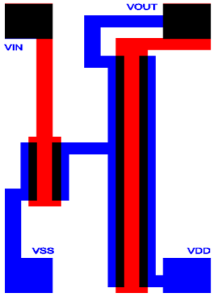
OFET



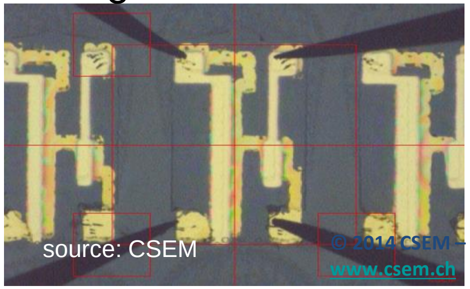


single OTFT





Voltage inverter



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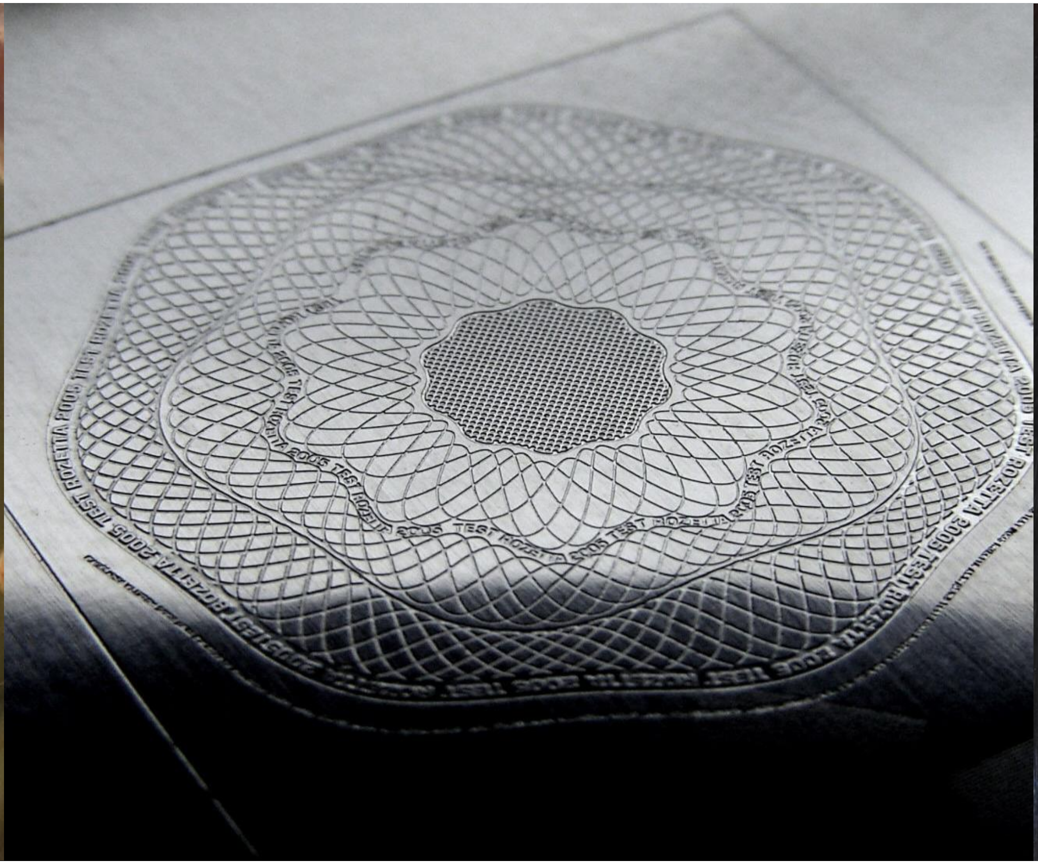
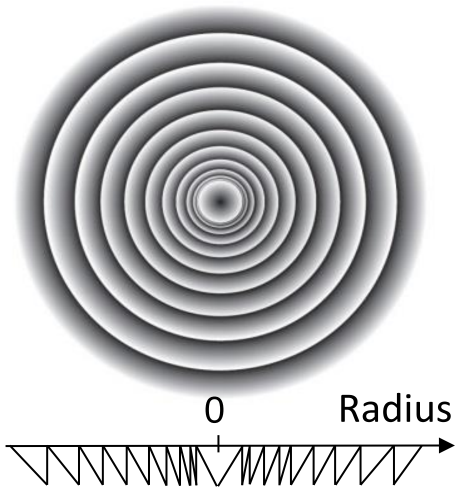
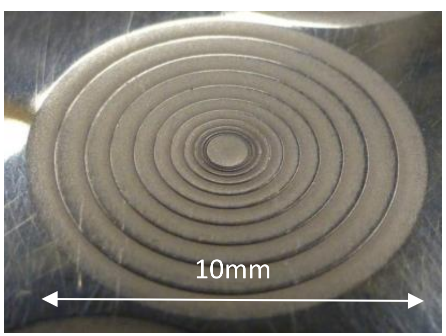


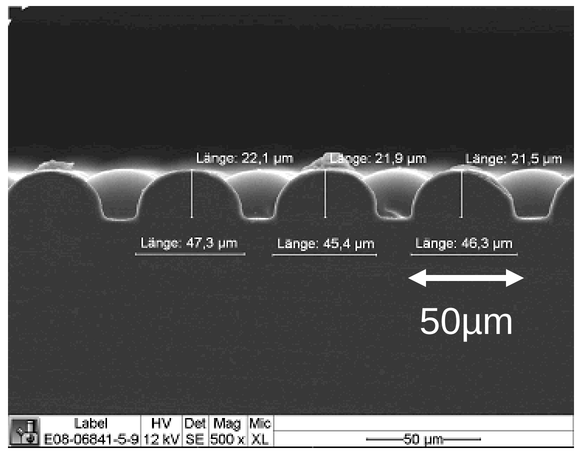
Fresnel Lenses

Digital Data
Grayscale - Depth





Diffusor foil (polycarbonate)
for displays

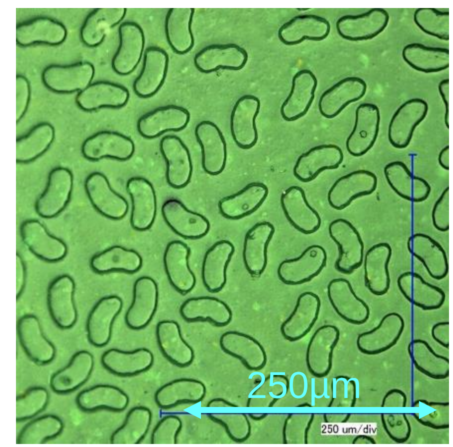


SEM image

depth:

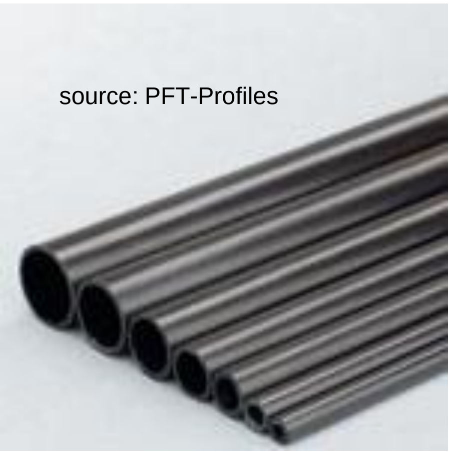
tool	30µm
structure on foil	22µm

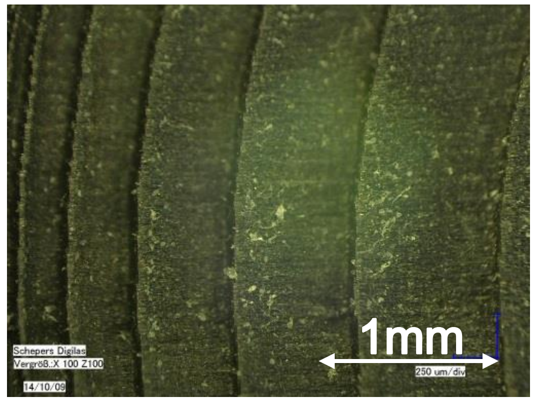
Effect foil:
Avoidance of fingerprints on touch screens

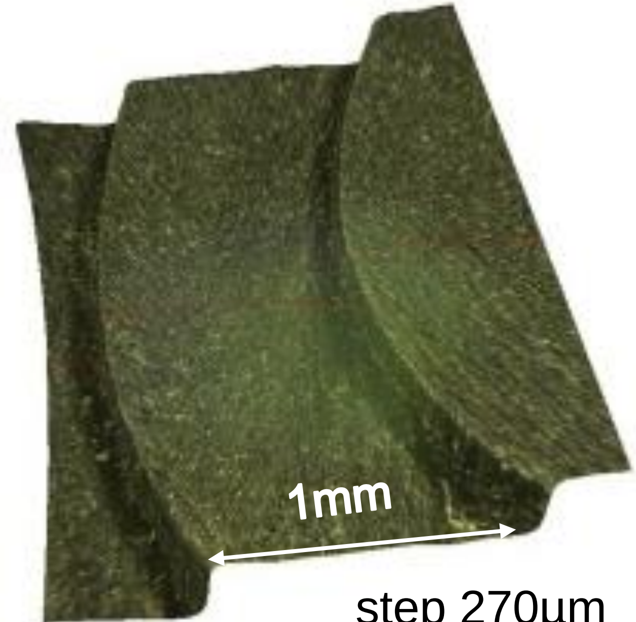


depth 2-3µm
length 40µm

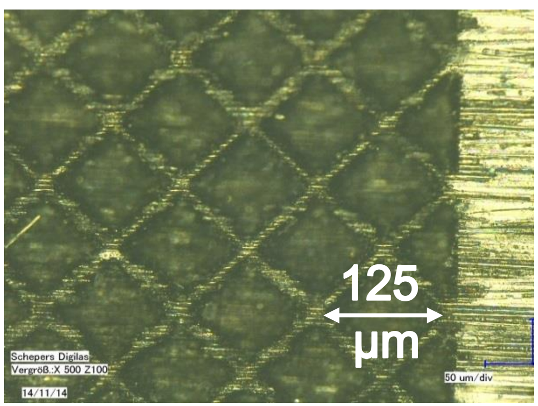
Carbon fiber reinforced plastic CFRP

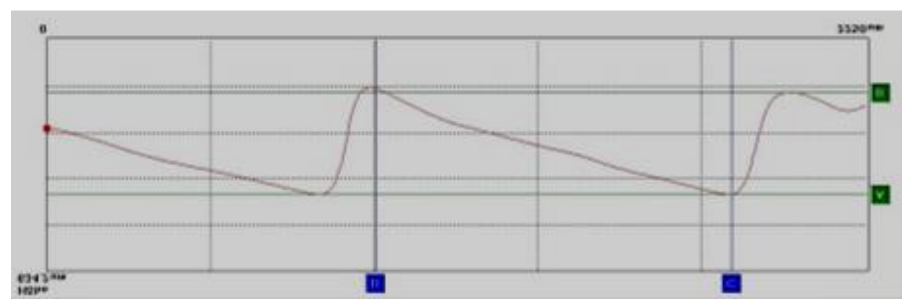






step 270µm

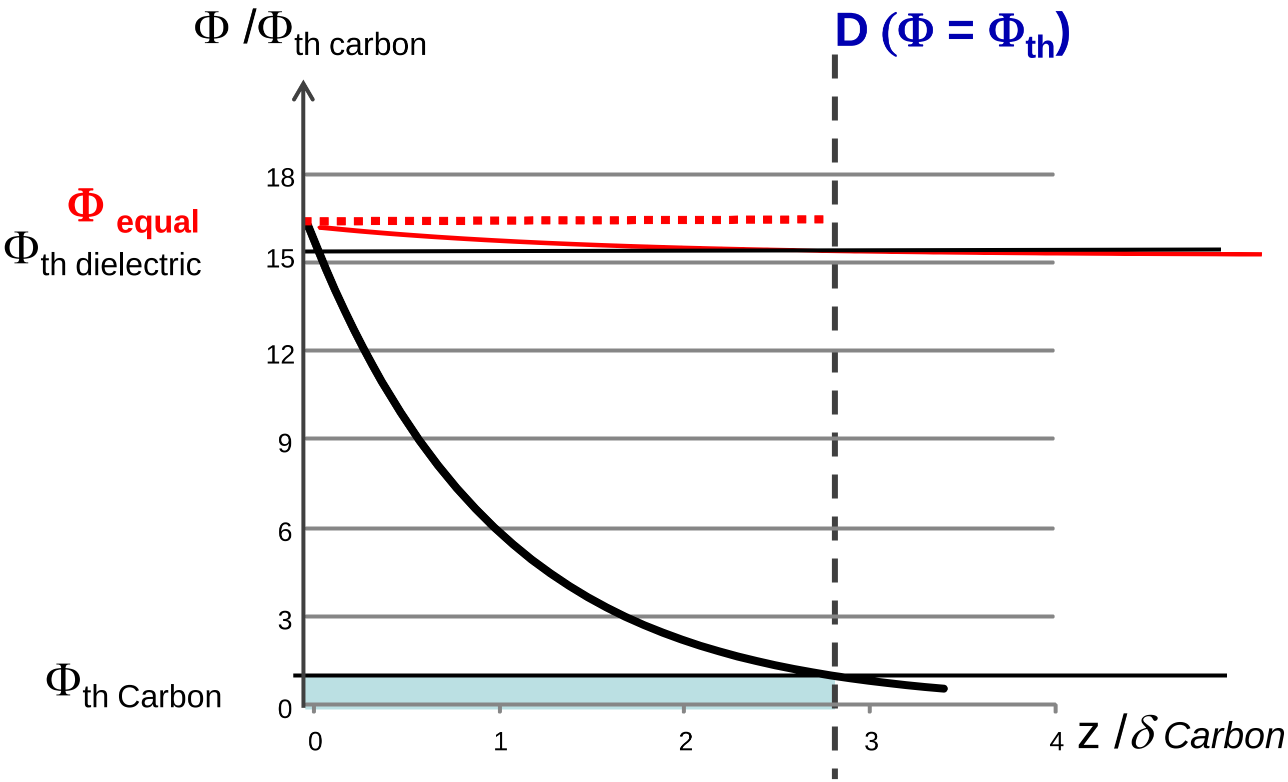




Simplified model (in case of Tophat beam profile, not including nonlinear effects)

$$\Phi(z) = \Phi(0) \cdot e^{-z/\delta}$$

$\Phi_{\text{equal}} \sim \Phi_{\text{th dielectric}}$

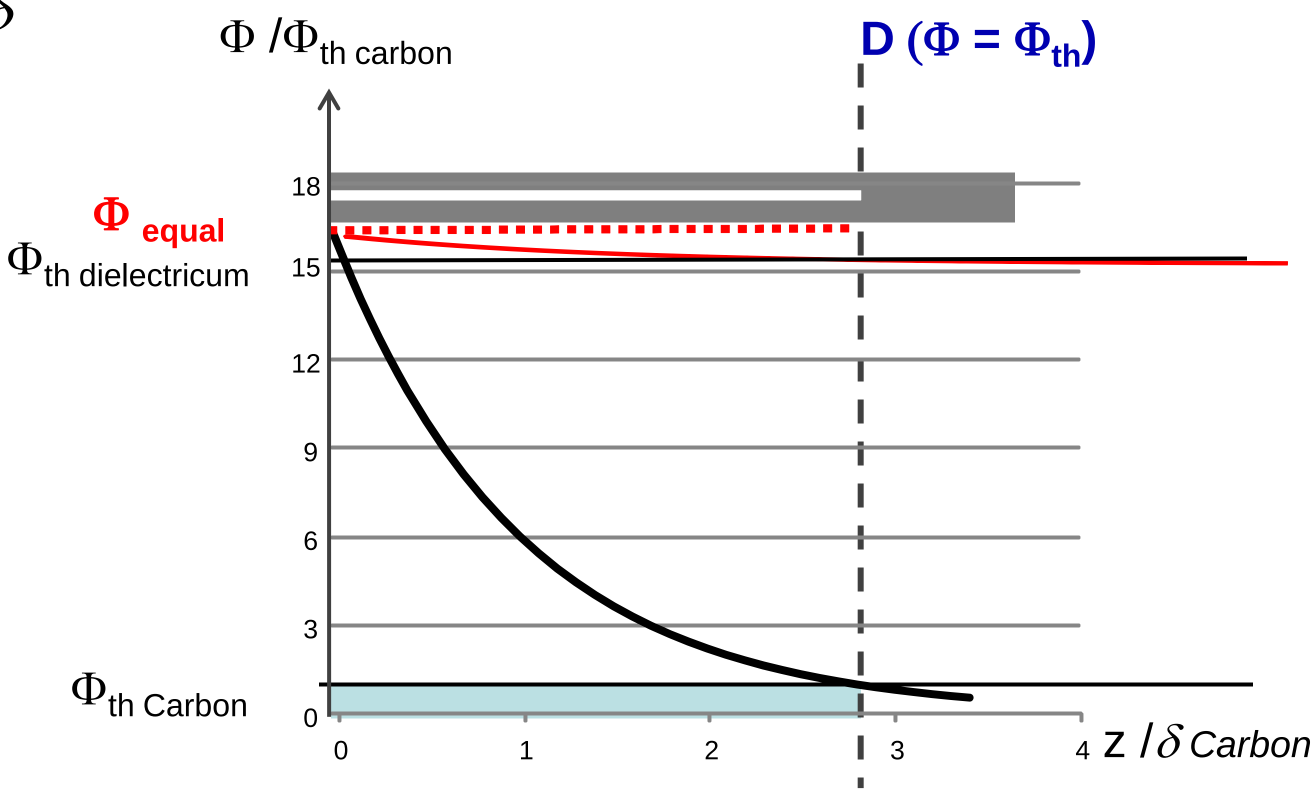


For Φ_{equal} the crossover of the Fluencies with the threshold fluencies is at same point D

Simplified model (in case of Tophat beam profile, not including nonlinear effects)

$$\Phi(z) = \Phi(0) \cdot e^{-z/\delta}$$

$\Phi_{equal} \sim \Phi_{th\ dielectrics}$



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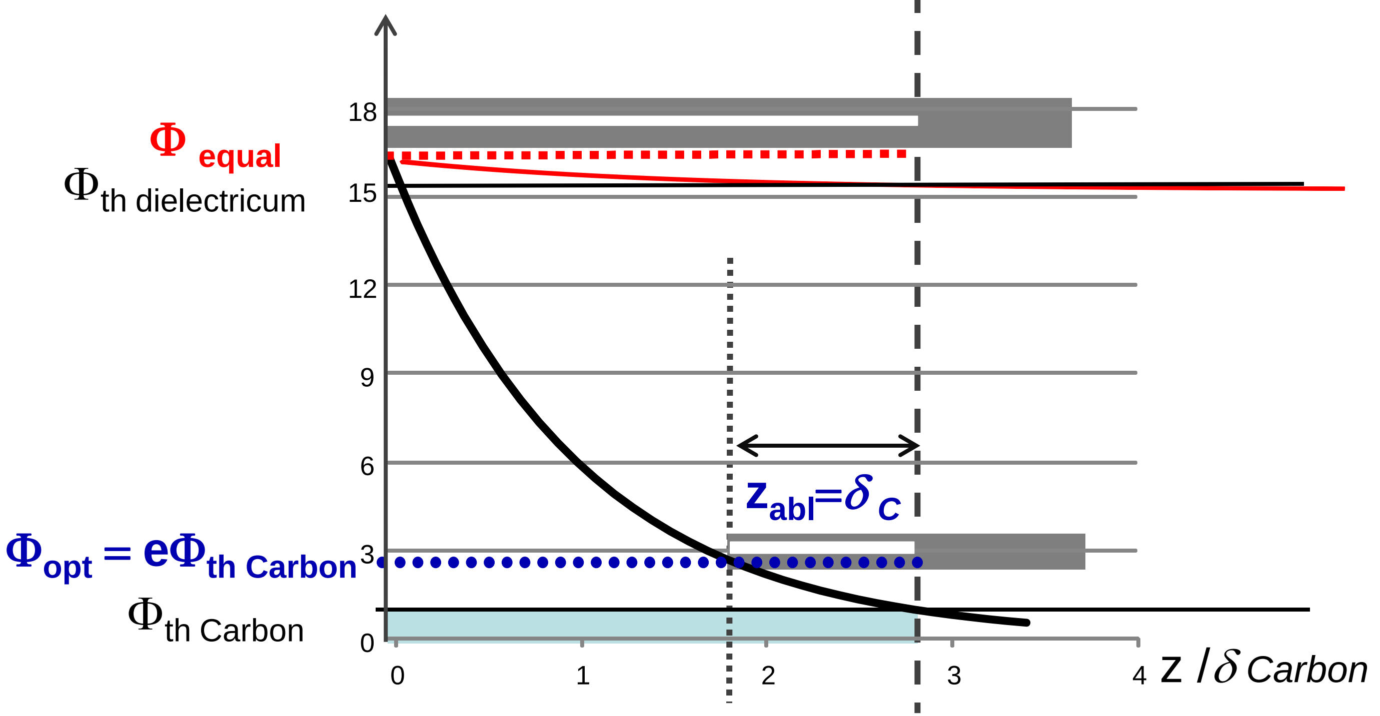

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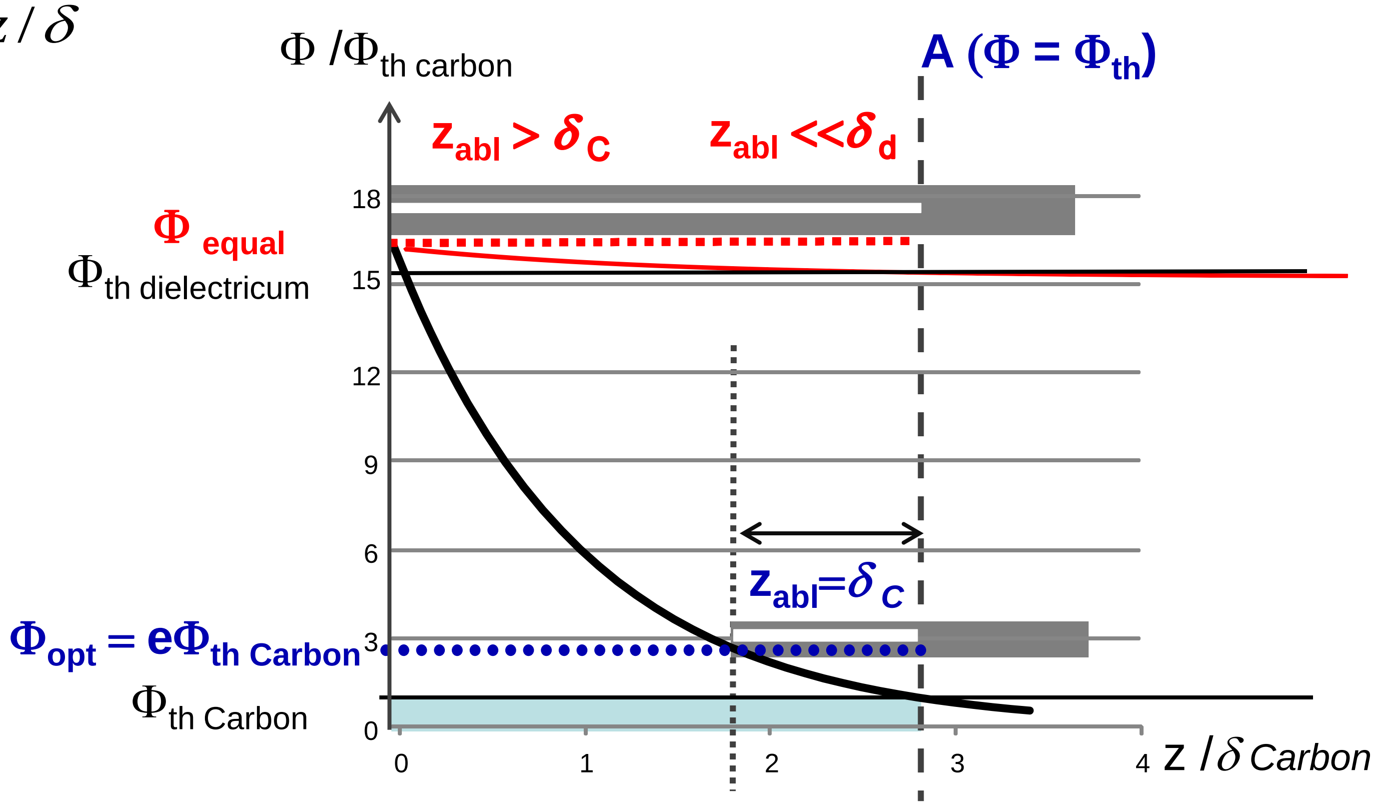

For Φ_{equal} the crossover of the Fluencies with the threshold fluencies is at same point D

Summary

Microstructuring of metals with ps laser can be optimized by:

- adjustment of fluence per pulse to match ablation depth with energy penetration depth δ

  → maximized ablation efficiency and minimized effects like CLP, heating losses

- Scaling up of throughput by higher laser power should be accompanied by

  → higher repetition rate and scan speed, bursts, larger focus size or multiple beams

- There is still development needed for upscaling the modulation rate and scan speed as well as for multiple beam concepts.

→ appolo

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Thank You!

Heliograph Holding, Munich