Empa
Materials Science and Technology

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

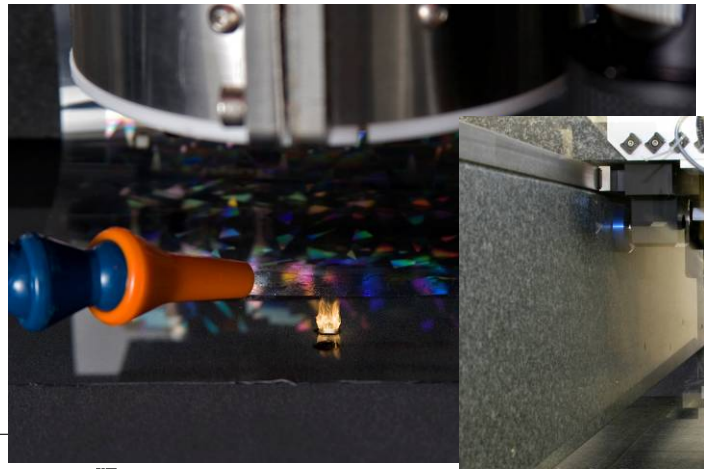
Laser Processing of Materials

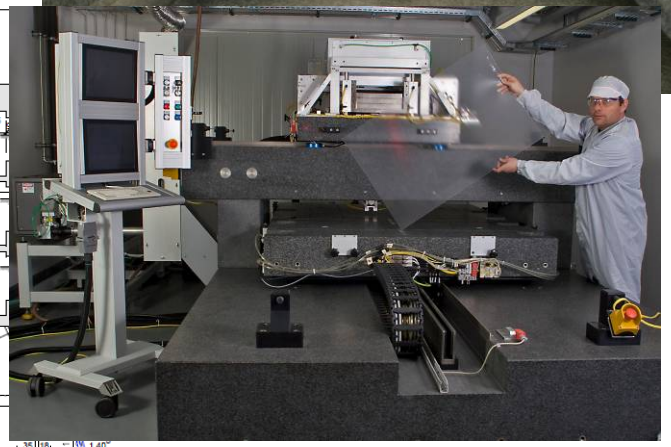
Applications: Ablation

Patrik Hoffmann

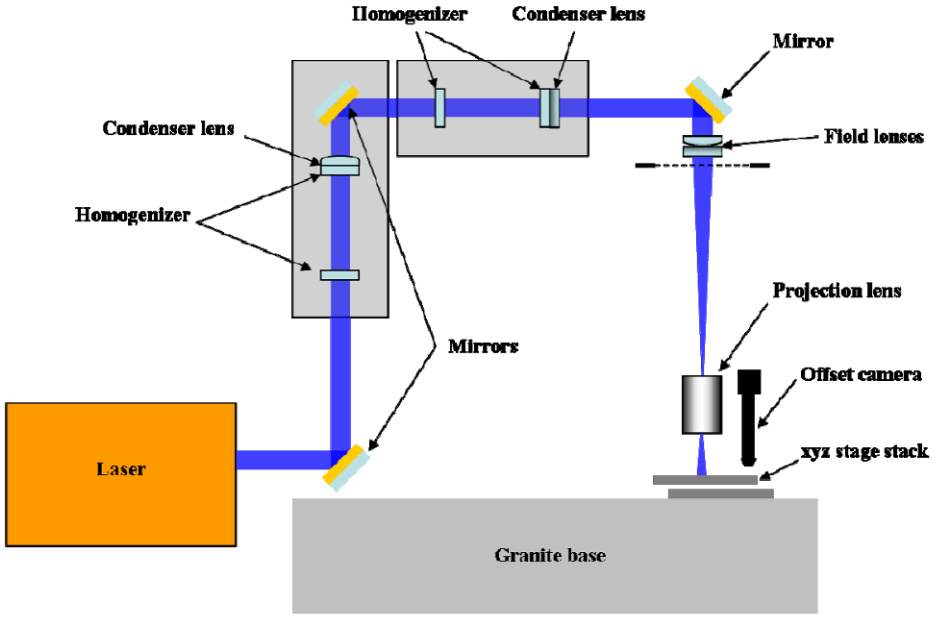
Installations in EMPA, Thun

New laser lab in building 862





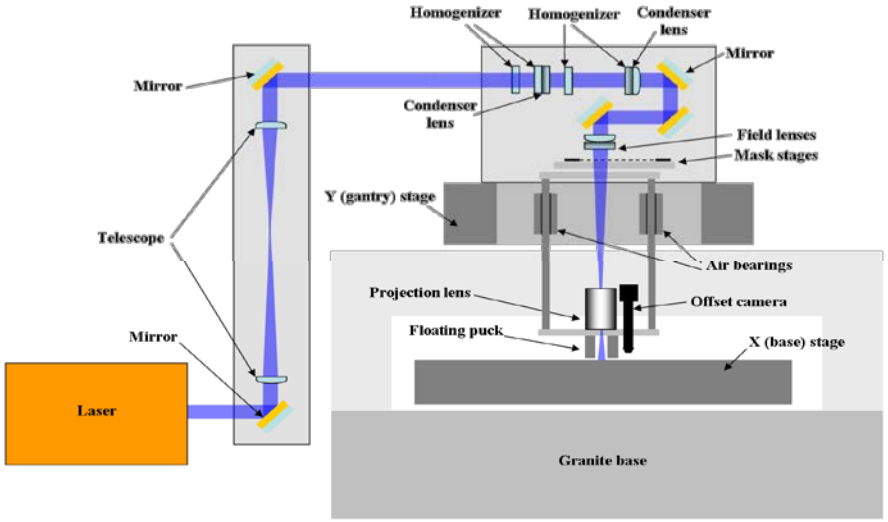
Exitech M8000 Micromachining System



Travel	400 mm
Accuracy	±0.50 µm
Repeatability	±0.20 µm
Straightness	±0.40µm
Flatness	±0.40µm

CREALAS
Smart Micromachining

Exitech PPM-601E Gen6 Tool



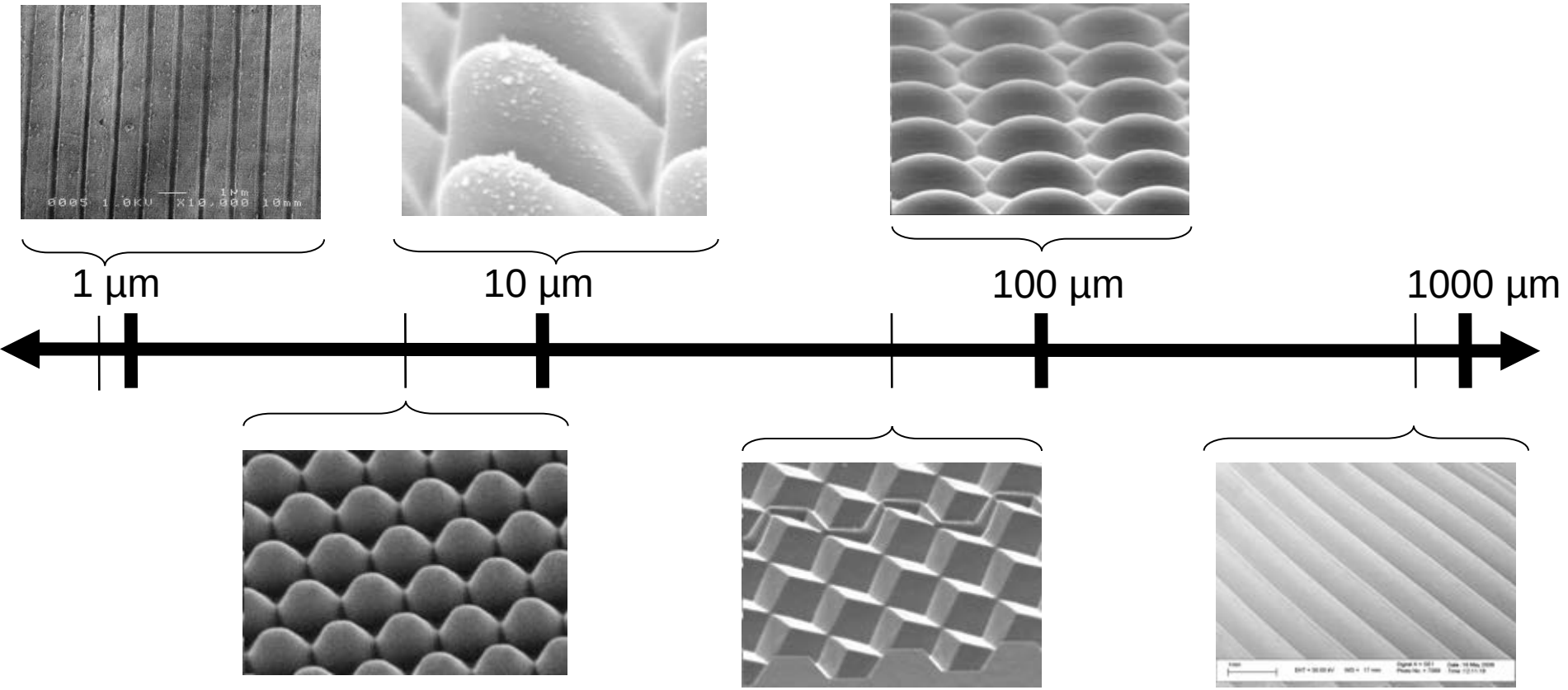
Specification	Unit	X-axis	Y-axis
		Spec	Spec
Travel	Mm	> 2200	> 1450
Payload	Kg	~ 115	~ 280
Speed	mm/s	200	360
Acceleration [1]	m/s^2	0,75	1
Resolution	µm	0,04	0,04
Bi-directional repeatability	µm	±2	±2
Accuracy (before calibration) [2]	µm	±4,5	±3
Straightness, bi-directional	µm	±2	±1,5
Flatness, bi-directional	µm	±5	±5
Roll, bi-directional	Arcs	2	1
Pitch, bi-directional	Arcs	2	1
Yaw, bi-directional	Arcs	2	2
Orthogonality (after calibration)	Arcs	2	

CREALAS Smart Micromachining

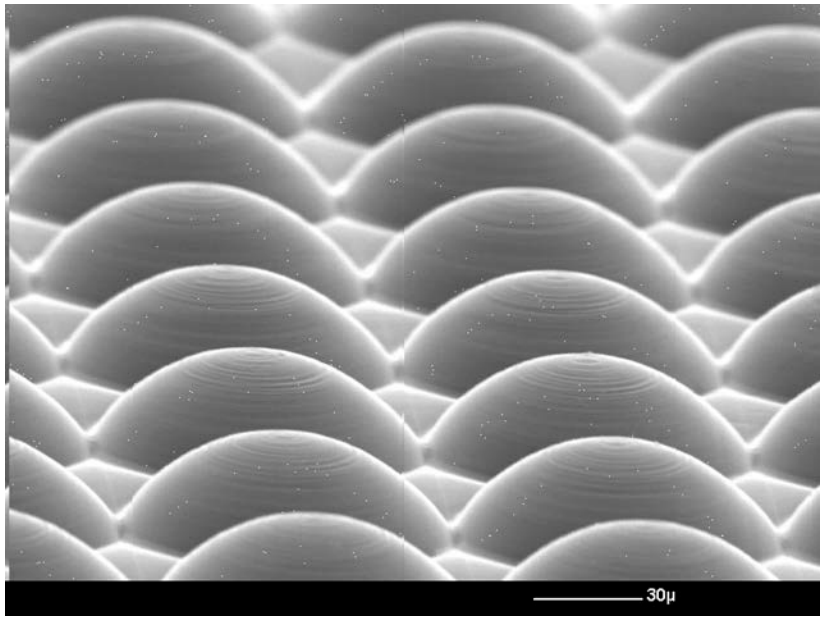
Some highlights

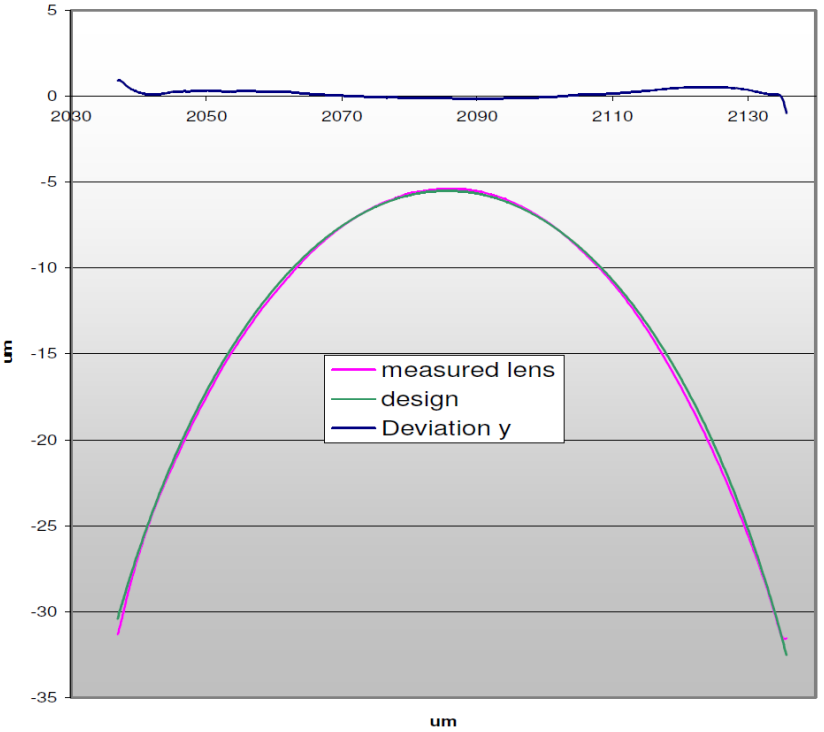
- 3 m^2 exposure area
- Ultra high precision: x/y axis < 40 nm resolution (laser interferometer based encoders)
- Repeatability 3 um over full travel (+/- 1.5 ppm)

Mask imaging from sub-microns to millimetres feature



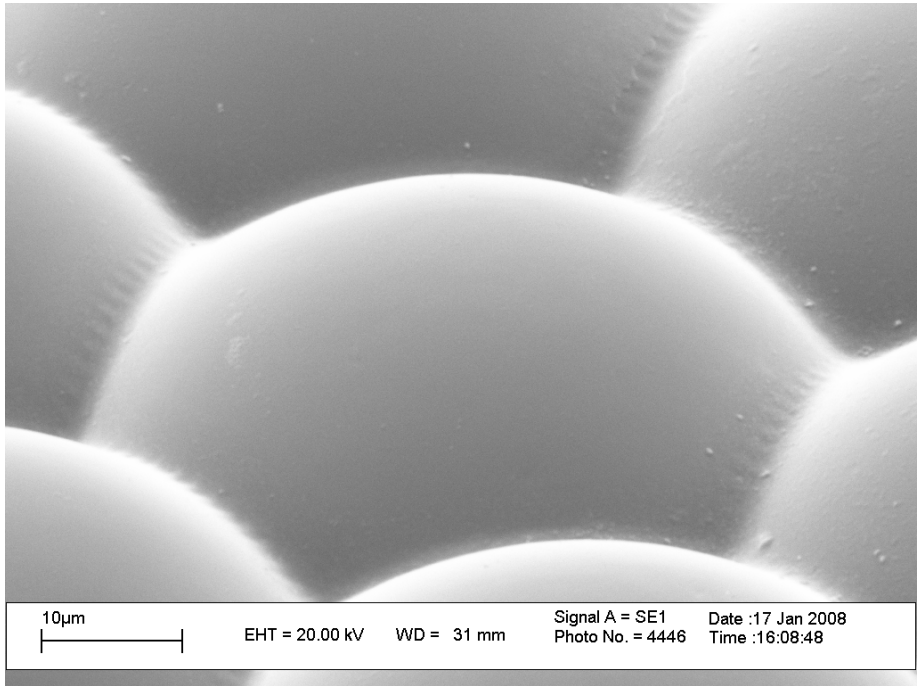
Feature quality: fit of target shape

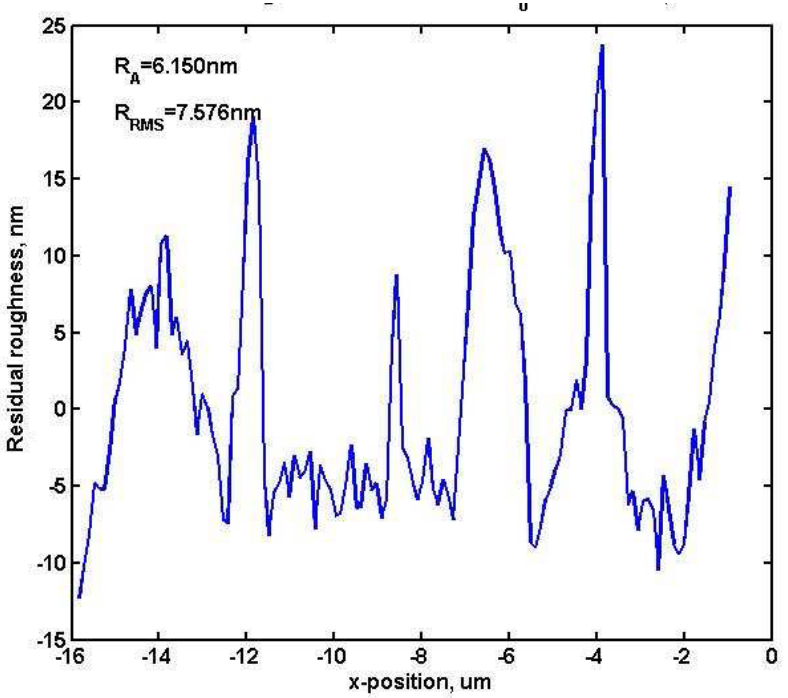




The average deviation from the best fit ROC is 147 nm with a ROC of 59.2 µm while the target is 60 µm.

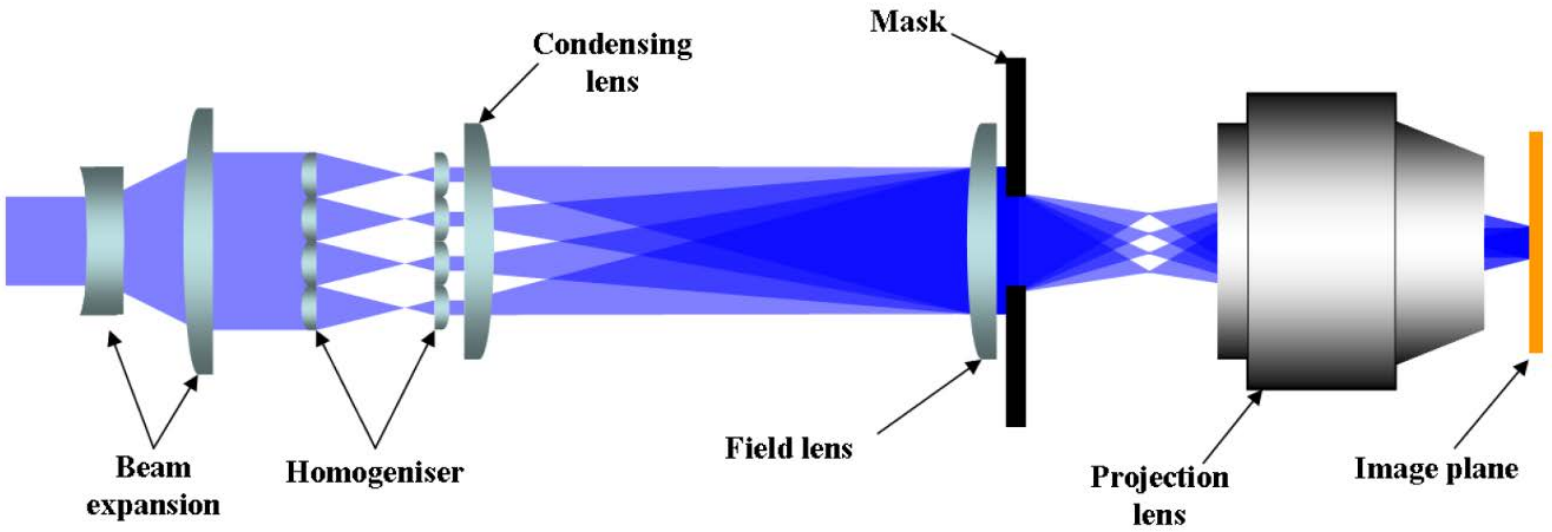
Feature quality: surface roughness



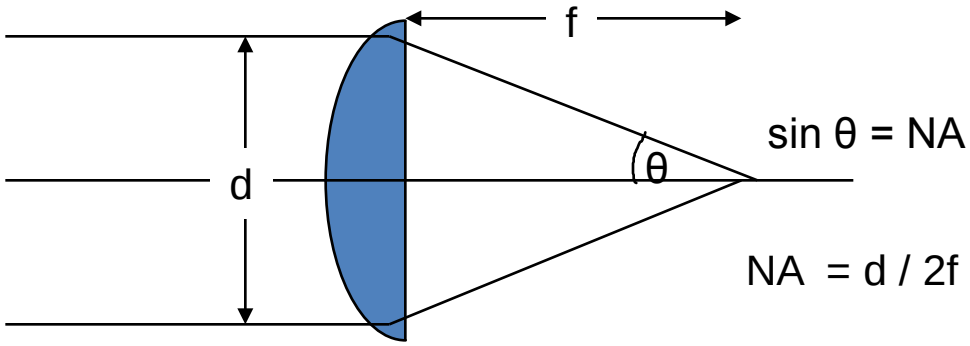


Courtesy of Imperial College London

Mask projection system



Focus control - resolution and N.A.



Diffraction Resolution Limit

$$d = \frac{k \cdot \lambda}{NA}$$

Depth of Field

$$DoF = \frac{\lambda}{NA^2}$$

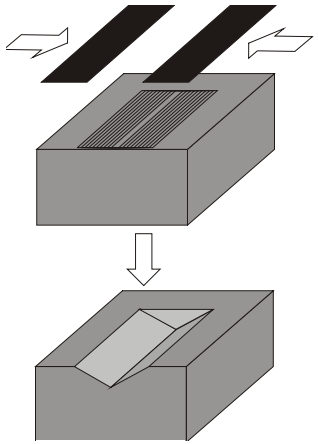
Resolution and Depth of Field Examples

λ	NA	k	Diffraction Resolution Limit	Depth of Field	Application
248 nm	0.1	0.8	2 µm	25 µm	Machining
193 nm	0.85	0.6	136 nm	270 nm	Lithography

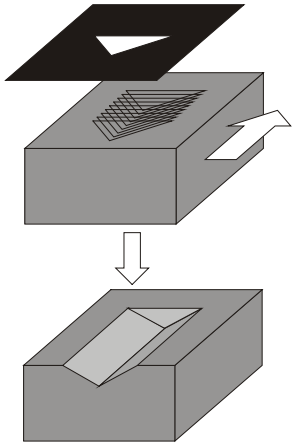
Advanced mask imaging

Projection ablation options for complex surface shapes

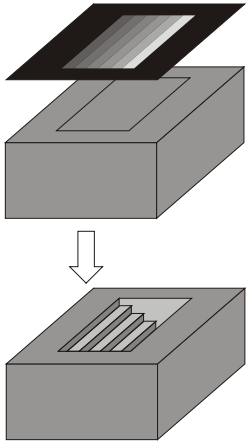
Variable aperture mask



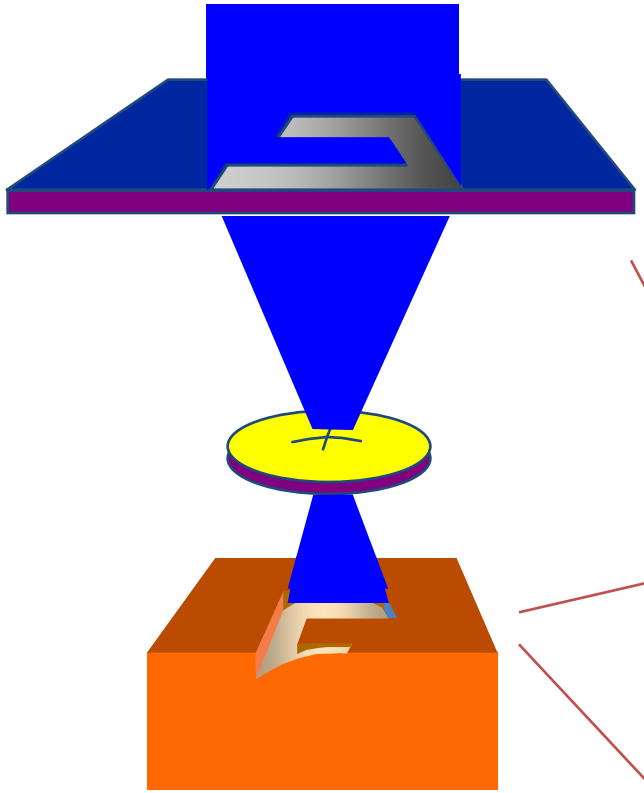
Scanned mask &/or workpiece

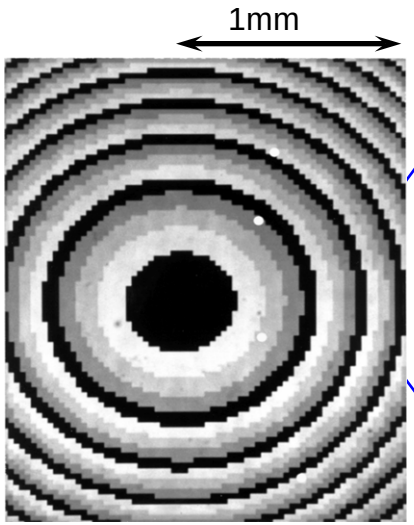


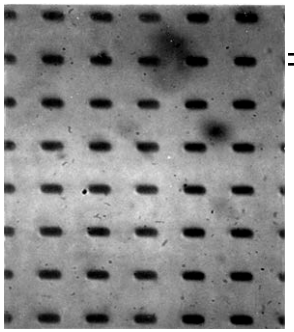
Gray scale mask

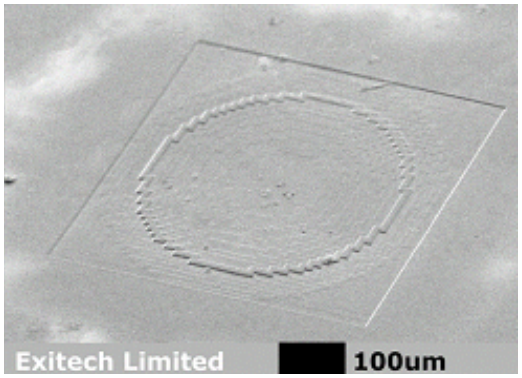


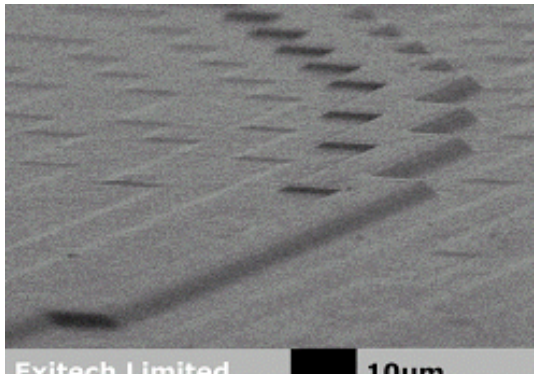
Intensity modulation of the imaged pattern









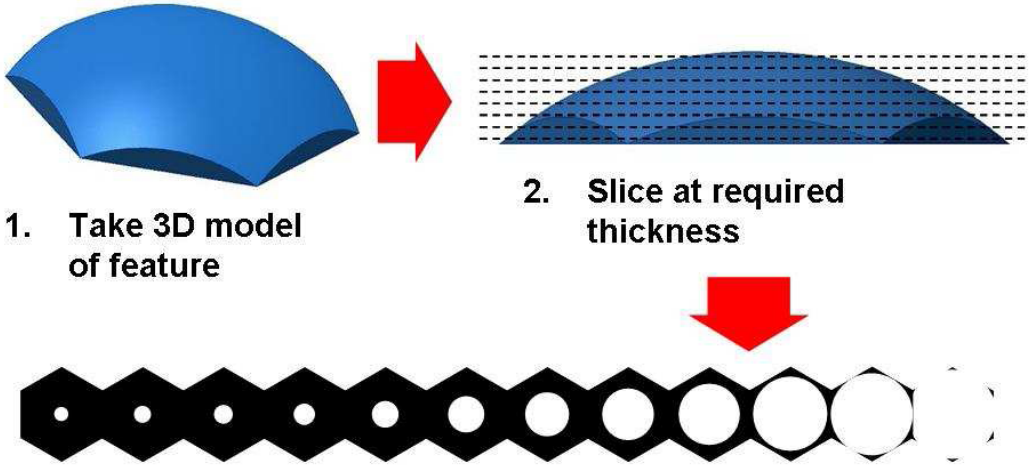


- Depth information incorporated in half-tone mask
- Transmission varied by changing hole size or density

8-level Diffractive Optical Element

Material: Polycarbonate; Laser: KrF excimer 248nm; Optics: x5, 0.13NA;

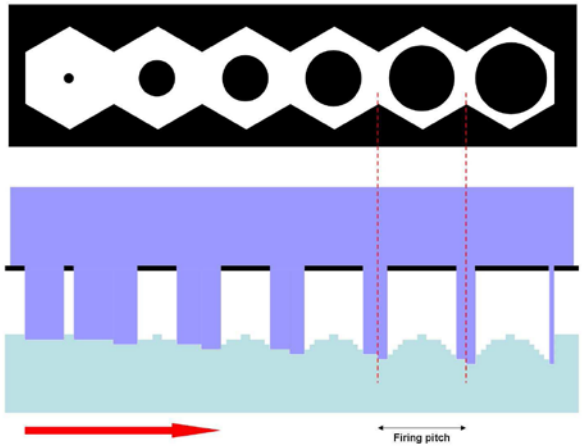
Synchronized Image Scanning (SIS)

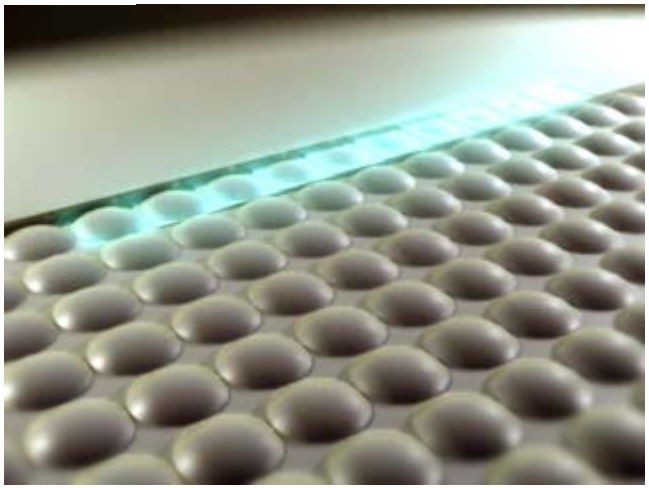


1. Take 3D model of feature

2. Slice at required thickness

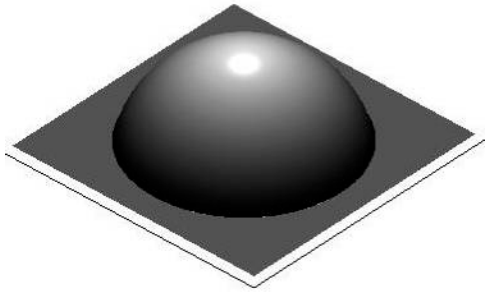
2. Array of contours to be placed on mask





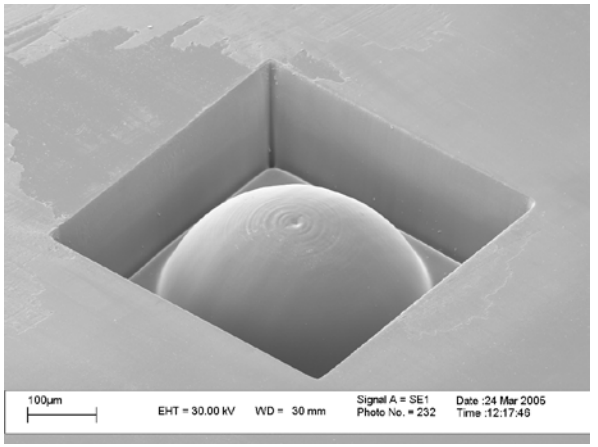
Experiment Design

desired design



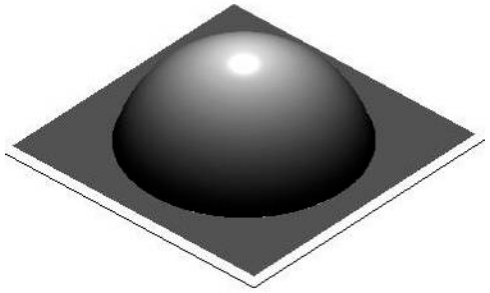
$h(x, y)$

resulting structure



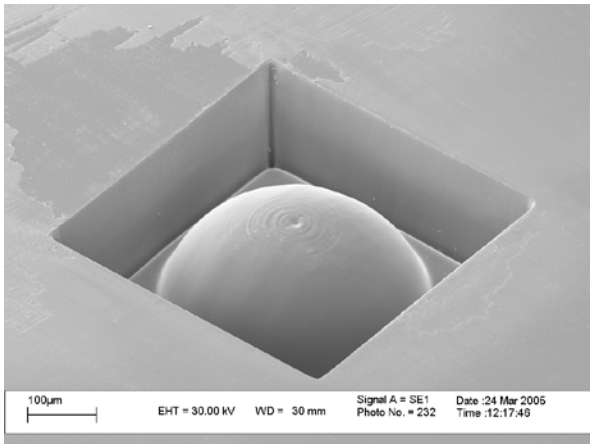
Experiment Design

desired design



$h(x, y)$

resulting structure



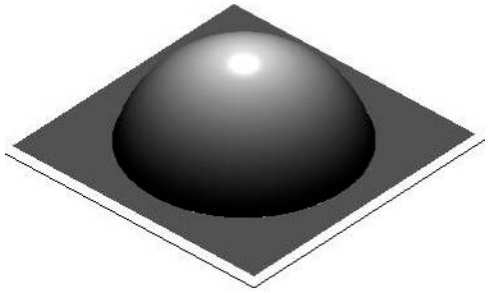
What do you need to know to make the process ?

about the laser …

about the material …

Halftone mask design

desired design

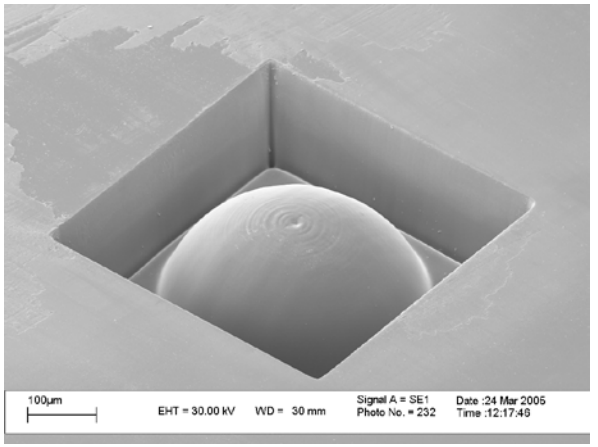


$h(x, y)$

mask transmission function

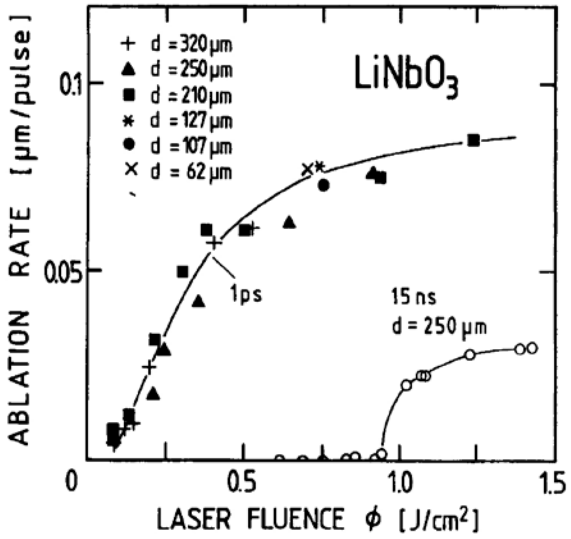
$$T(x,y) = \frac{1}{F_0 N} f^{-1}\left[h(x,y)\right]$$

resulting structure



$d = f(F)$

ablation curve



h	designed shape
d	ablation depth per pulse
N	number of pulses
F	laser fluence
F_0	laser fluence before mask
f	response function
f^{-1}	inversed response function

Capability summary

- Ablation
  - Feature sizes: 200 nm to a few mm
  - Feature height or depth *z*: <50 nm – 250 µm
  - Direct laser cutting of 3D features
  - Thin film patterning
- DUV lithography
- Large area processing
  (up to 2000 mm x 1500 mm)