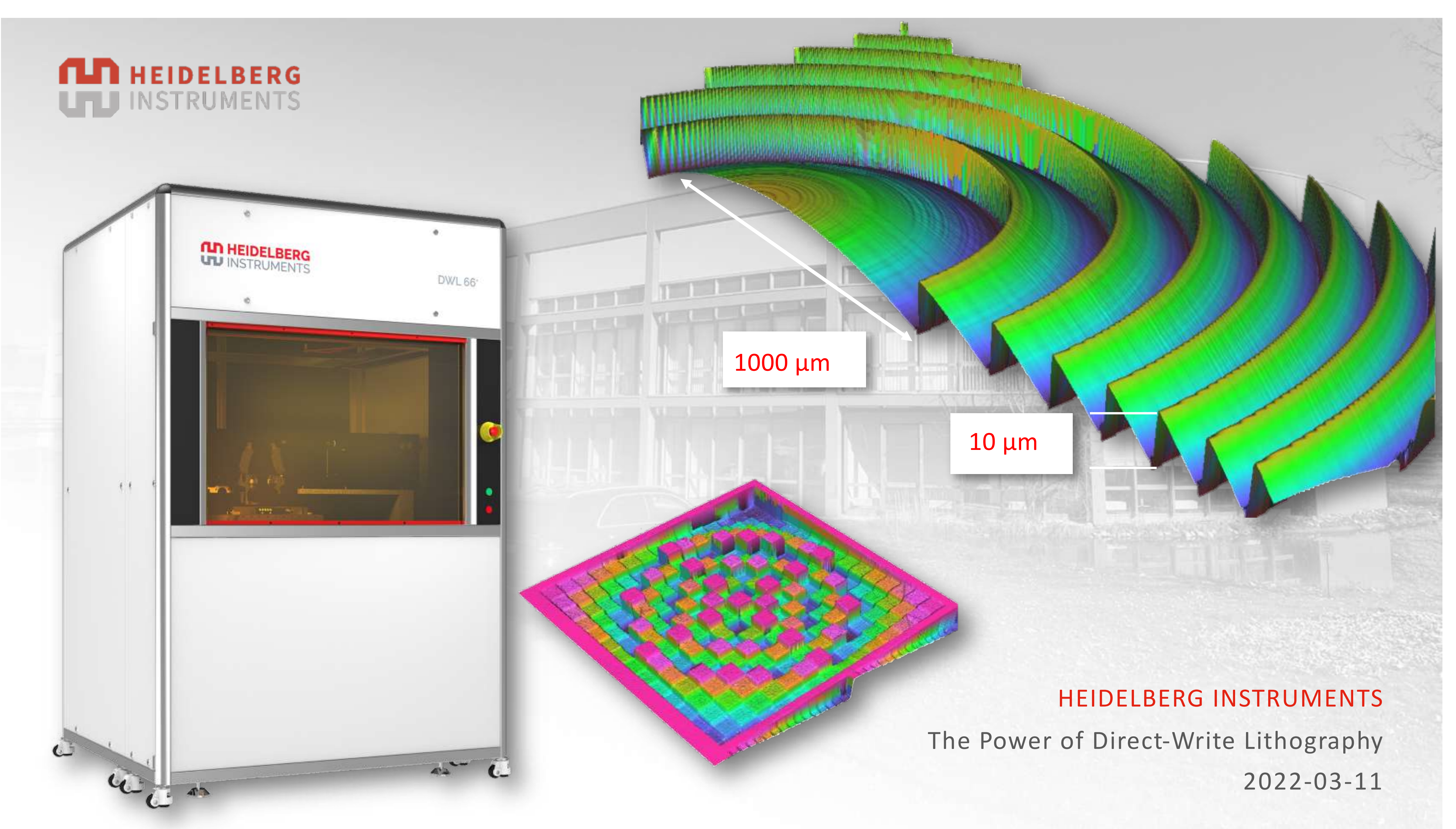
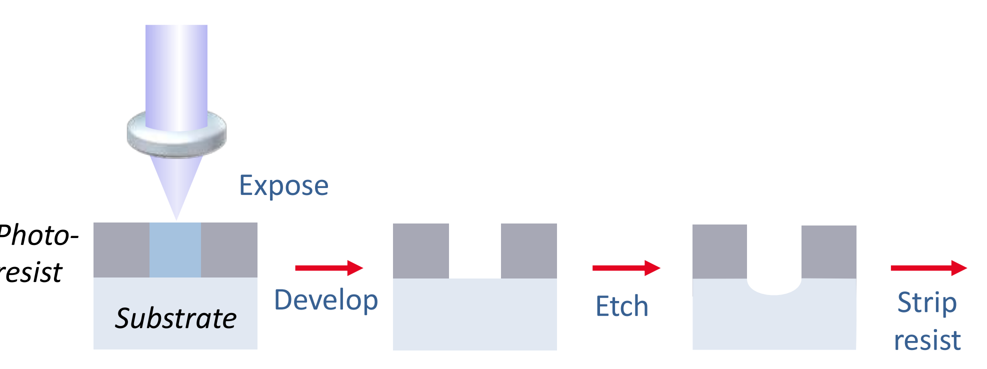
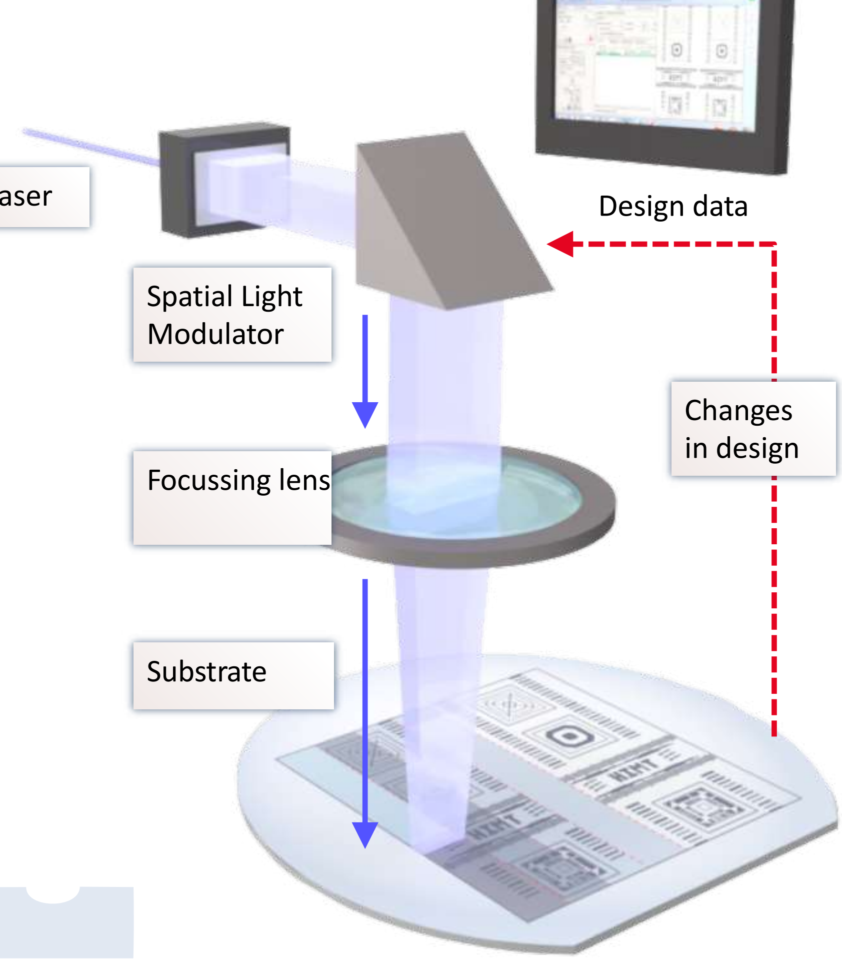

HEIDELBERG
INSTRUMENTS
HEIDELBERG
INSTRUMENTS
DWL 66+
1000 µm
10 µm
HEIDELBERG INSTRUMENTS
The Power of Direct-Write Lithography
2022-03-11

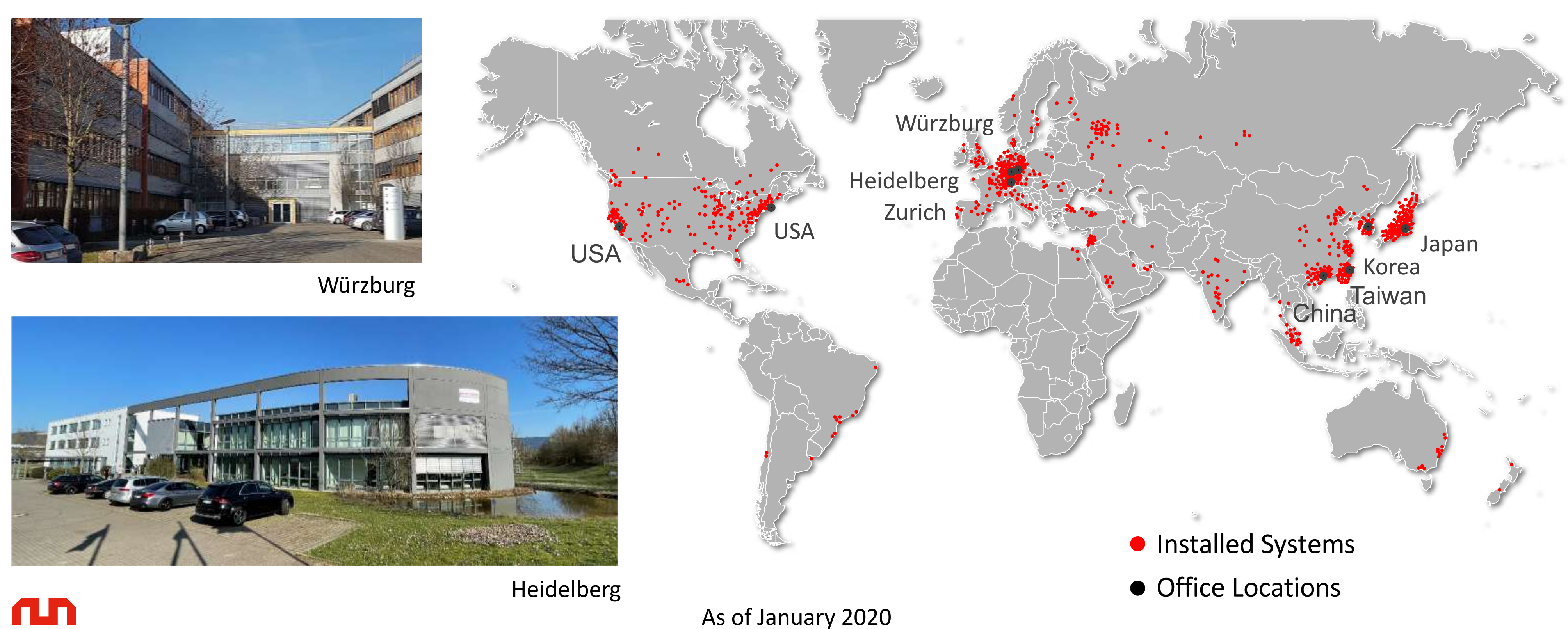
Heidelberg Instruments in a Nutshell

- World leader in the development and production of high-precision micro- and nanolithography systems
- Extensive know-how in developing customized lithography solutions
- More than 250 employees worldwide
- 50 million Euros turnover in 2020
- Founded in 1984
- More than 1000 systems in more than 50 countr





Heidelberg Instruments Worldwide

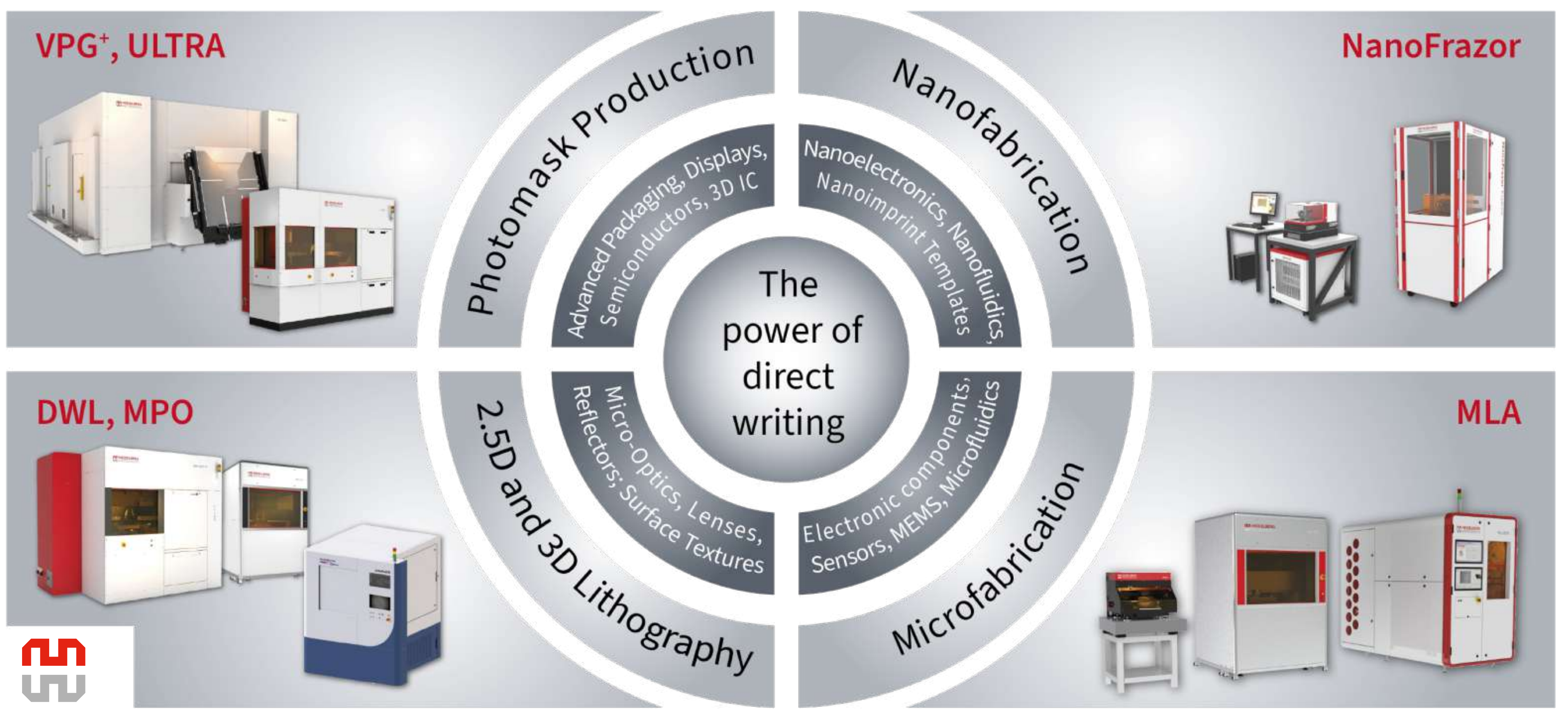


Würzburg

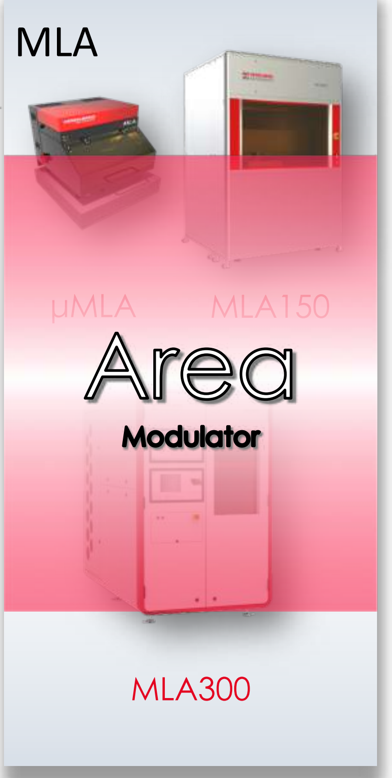
Heidelberg

As of January 2020

Heidelberg Instruments Product Portfolio



Heidelberg Instruments Product Lines Overview



HEIDELBERG INSTRUMENTS
DWL 2000/4000/8000GS
The High Resolution Pattern Generators
for Grayscale Lithography
DWL 66+
Ultimate Lithography
Research Tool
Beam
Modulator
Our systems for direct
writing and low
volume mask making –
the DWL series

Acousto-optic modulator and deflector

AOM

Acousto-optic deflector

AOD

0. order

1. order

φ

scan

$$\sin\varphi = \frac{\lambda}{2d} = \lambda\frac{f}{2c_s}$$

RF-Voltage

f [MHz]

t [µs]

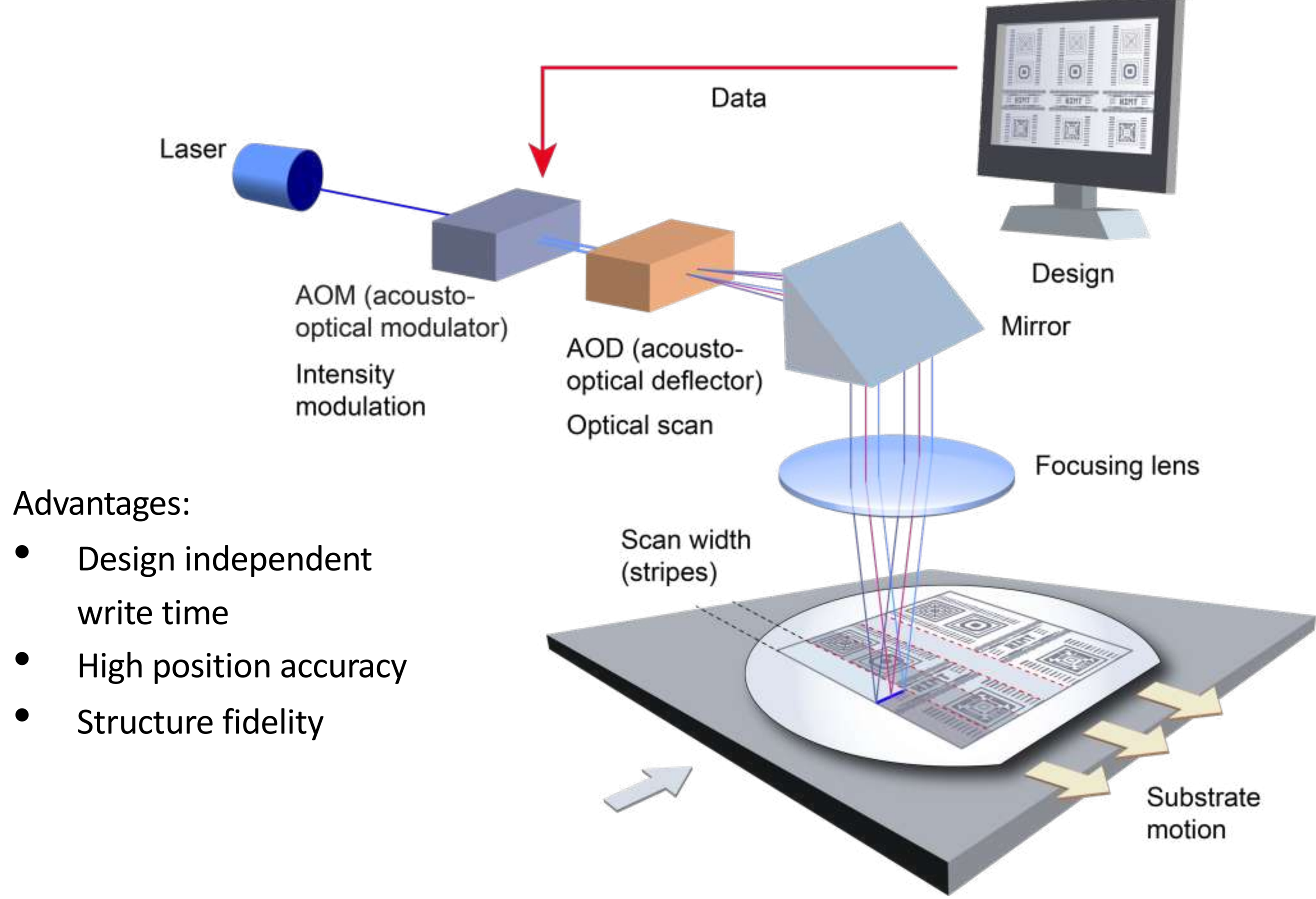
RF-Voltage

f [MHz]

t [µs]

Acousto-optic modulator

Exposure strategy: The raster scan



Advantages:

- Design independent write time
- High position accuracy
- Structure fidelity

Exposure strategy: The raster scan

y

Stage Position

x

ULTRA

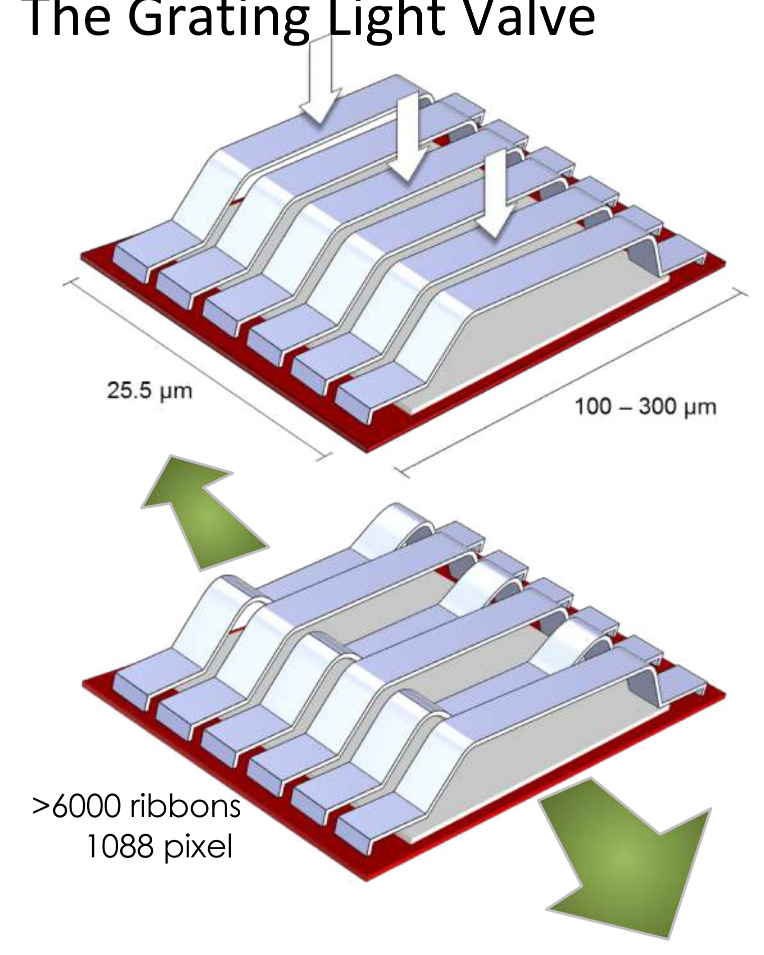
Semiconductor Laser
Mask Writer

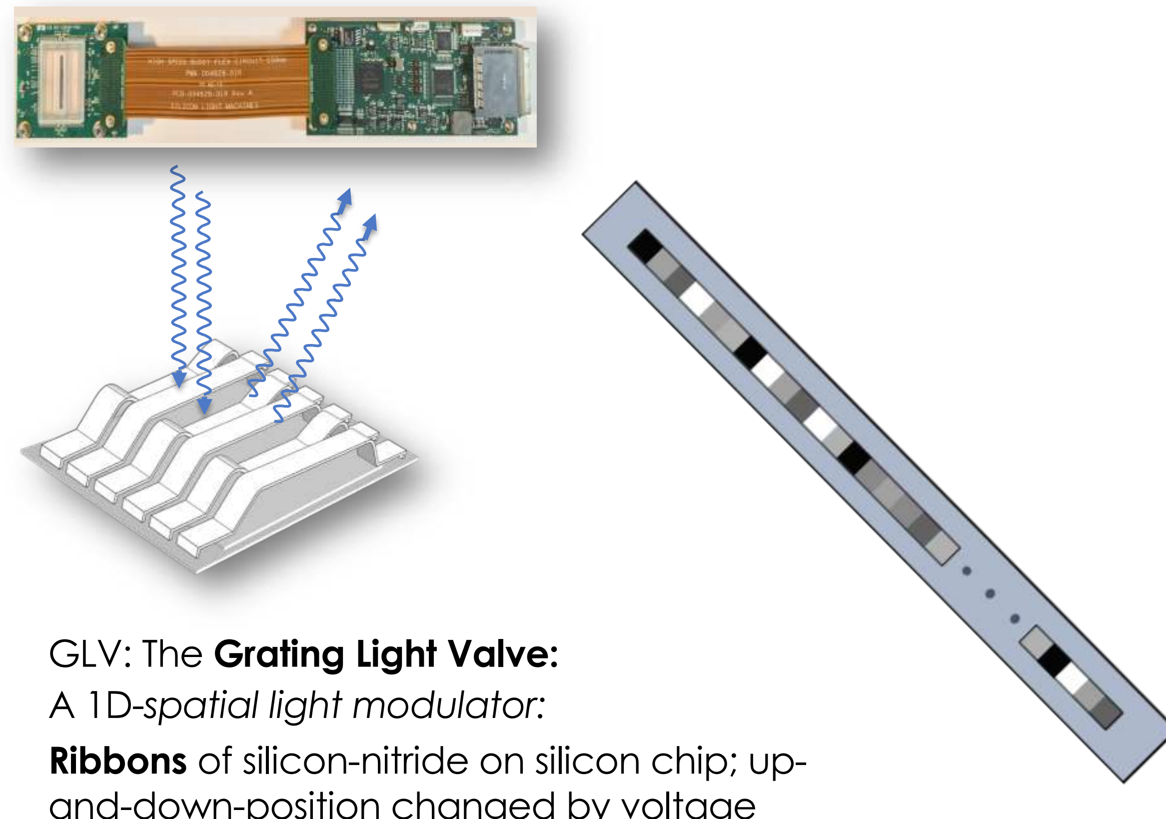
Line Modulator

Small Area
olume Pattern Generators

Large Area
Volume Pattern
Generators

The Grating Light Valve





GLV: The **Grating Light Valve:**

A 1D-*spatial light modulator:*

Ribbons of silicon-nitride on silicon chip; up-and-down-position changed by voltage

→ Groups of ribbons form a diffractive **grating**

→ 3 variable and 3 fixed ribbons per pixel

→ Modulating laser light as per design data

Exposure strategy VPG+: Raster scan, continuous scrolling

Laser light source

Spatial Light Modulator - GLV

Design data

Mirror

Focusing lens

Design and operating software

Scan width

Scan direction

Stage motion

Writing Process

Exposure strategy VPG$^+$:

Raster scan, continuous scrolling

y

Stage Position

x

µMLA
MLA150
MLA300
Maskless Aligners

Area
Modulator

Exposure strategy MLA series

Laser light source

Data

Spatial Light Modulator

Mirror

Design

Focusing lens

Scan width (stripes)

Bidirectional writing process

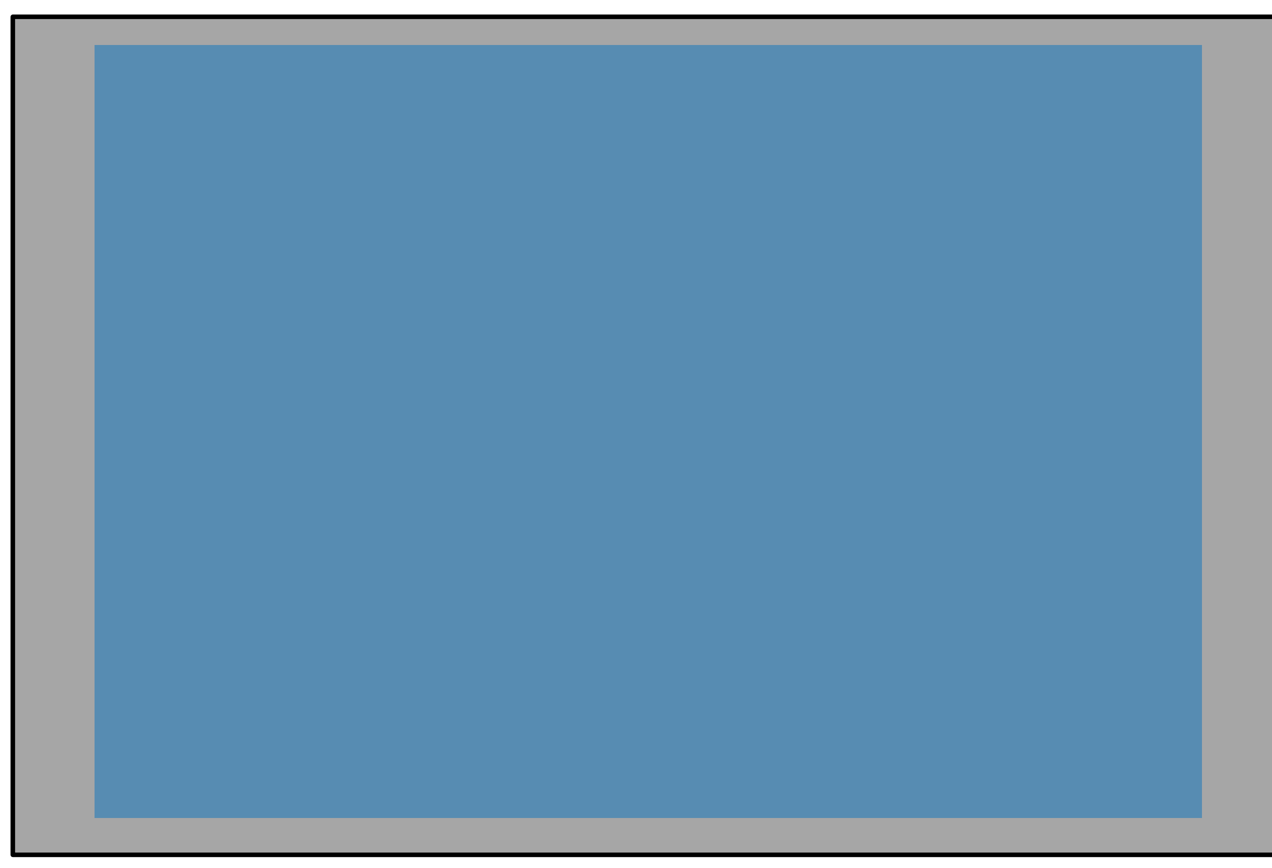
Write direction

Direction of stage travel

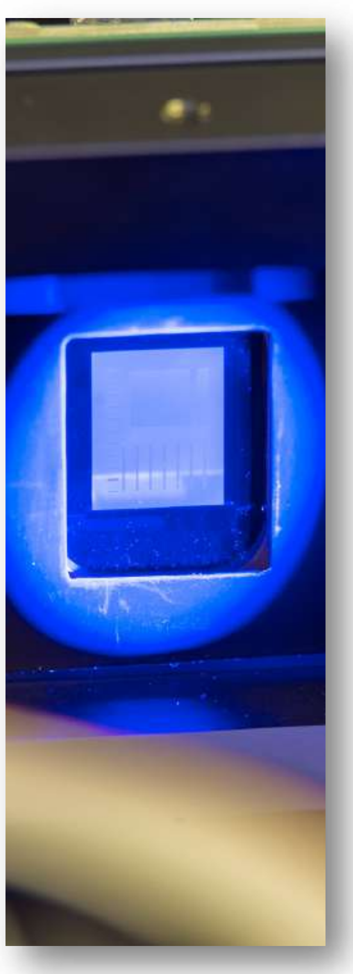
SPEED

The DMD™

Exposure strategy MLA series

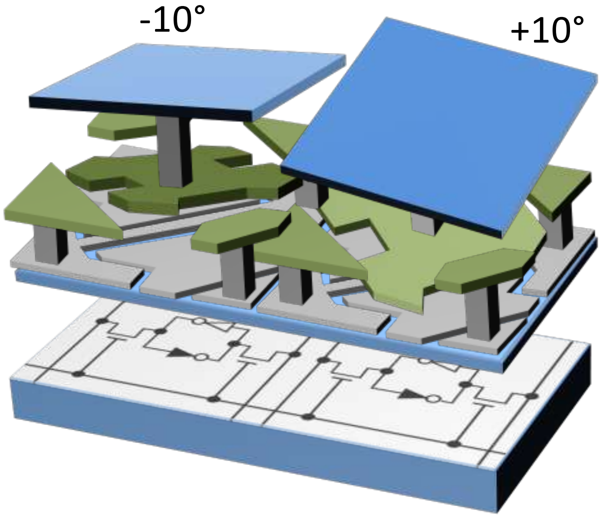


The DMD™



DMD™ = digital multimirror device

- MEMS device
- Each pixel consists of an aluminum micromirror
- Two bias electrodes tilt the mirror either to +10° or -10°
- ON (+10°): Mirror reflects light into lens, pixel is bright
- OFF (-10°): No reflection, pixel is dark
- DMD contains more than 442,000 micromirrors



Simplified representation of two tilted mirrors (i.e. two pixels) in a Texas Instruments DMD™

Schematic adapted from Marc J. Madou, Fundamentals of Microfabrication and Nanotechnology, Volume II, © CRC Press 2012

MPO100

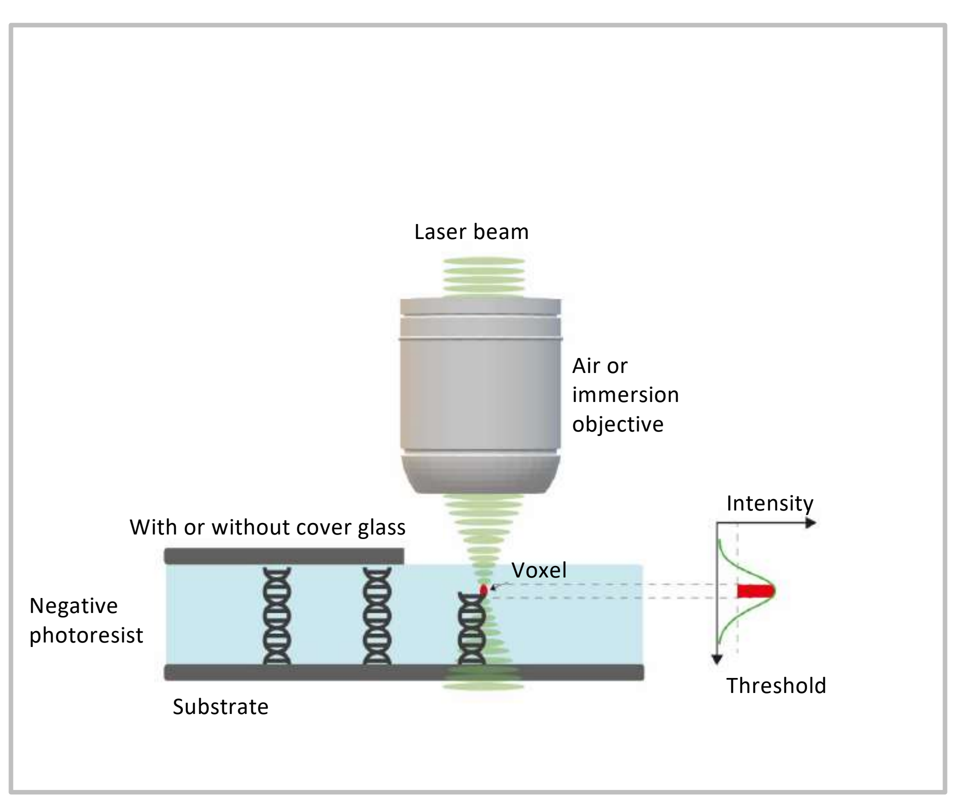
Two Photon Polymertization

TPP

Modulator

Core Technology | Two-Photon Polymerization (TPP)

- Two-Photon Polymerization (TPP) is a **Direct Laser Writing (DLW)** technology. With TPP, the light-matter interaction only takes place within the volume of a **focused laser spot.**
- The simultaneous **absorption of two photons** in the focused spot triggers the **locally confined polymerization** of an exposed photoresist.
- The laser focus can be moved through the volume of the photoresist along all three spatial dimensions. **Complex 3D structures are written along the laser's trajectory**, using light like a brush.
- Thanks to its versatility, TPP fabrication has applications in many fields, including **micro-optics, photonics, micro-mechanics and biomedicine**.



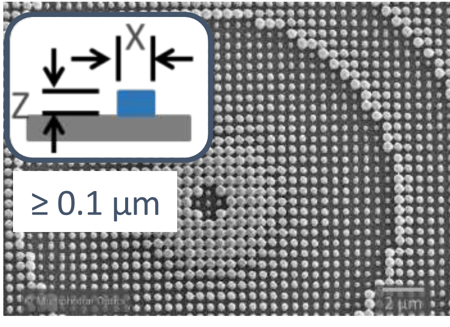
Simplified illustration of the Two-Photon Polymerization (TPP) process.

MPO TPP Fabrication Process | Unparalleled design freedom

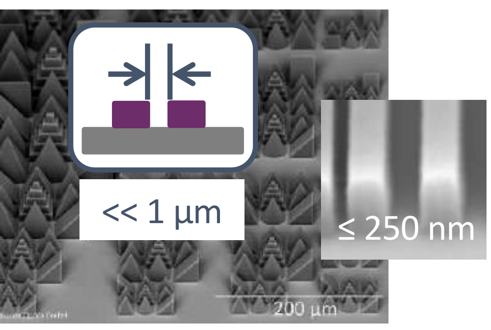
Nano – Micro – Meso – Macro

Multiphoton Optics' technology removes limitations in design and enables the creation of free-form 3D structures on virtually any substrate including active devices.

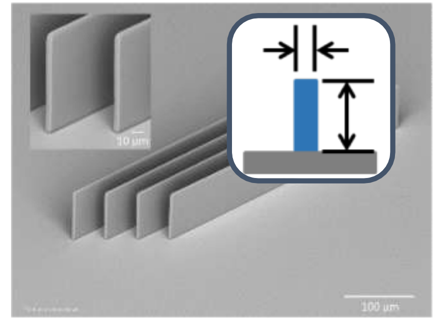
Features sizes can be as tiny as 0.1 µm



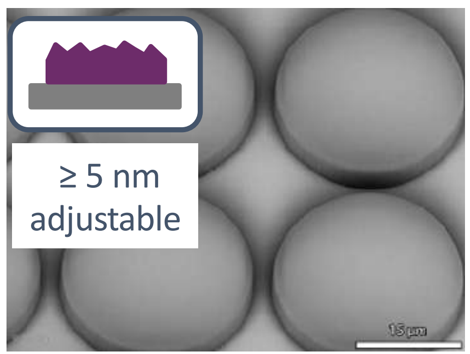
Objects can be much closer than 1 µm



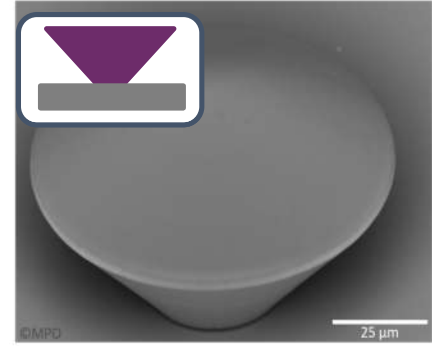
Extreme aspect ratios of 16:1 and above



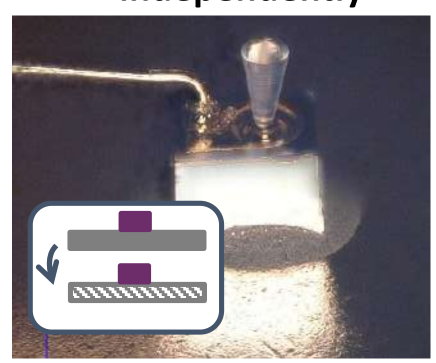
Achievable roughness can be adjusted as smooth as 5 nm



Overhangs do not require supporting

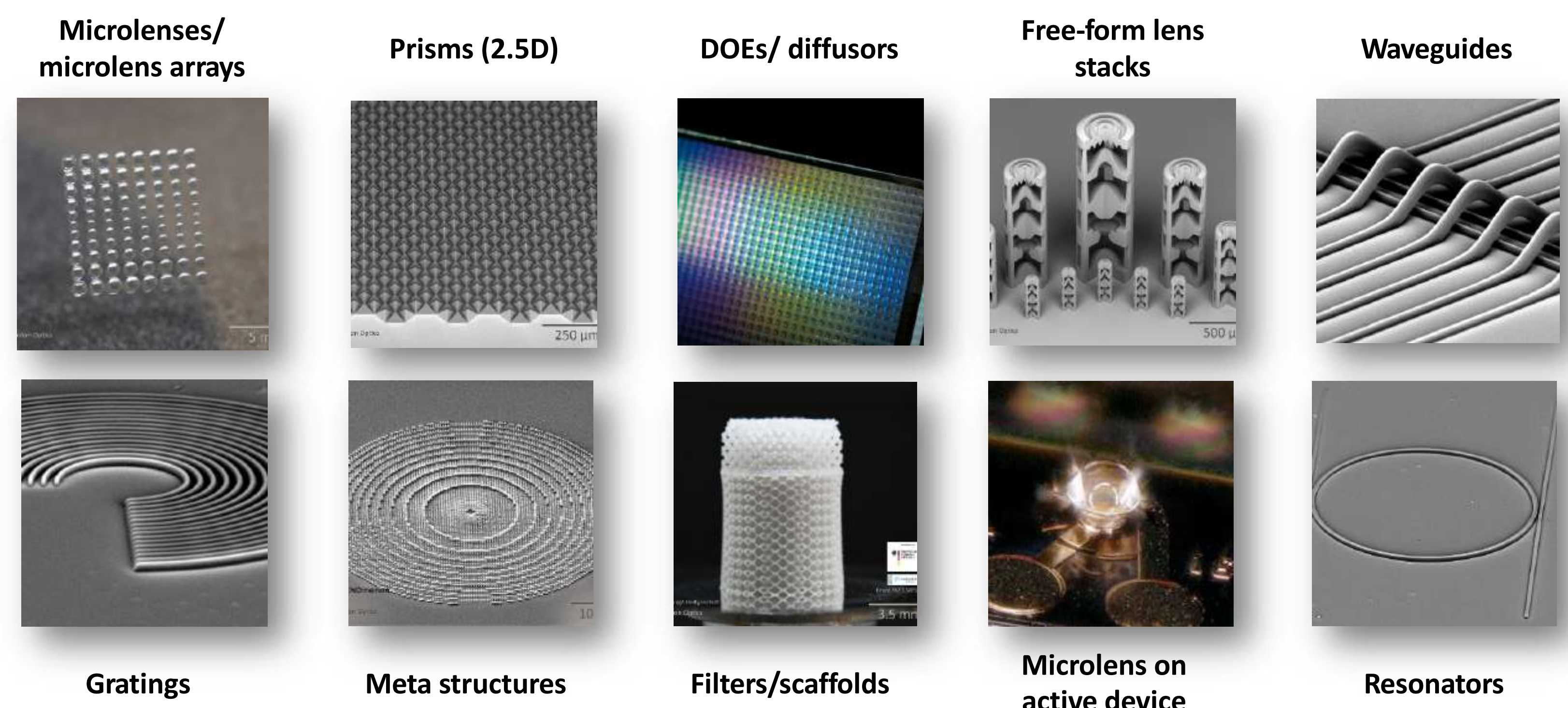


Substrate can be chosen independently



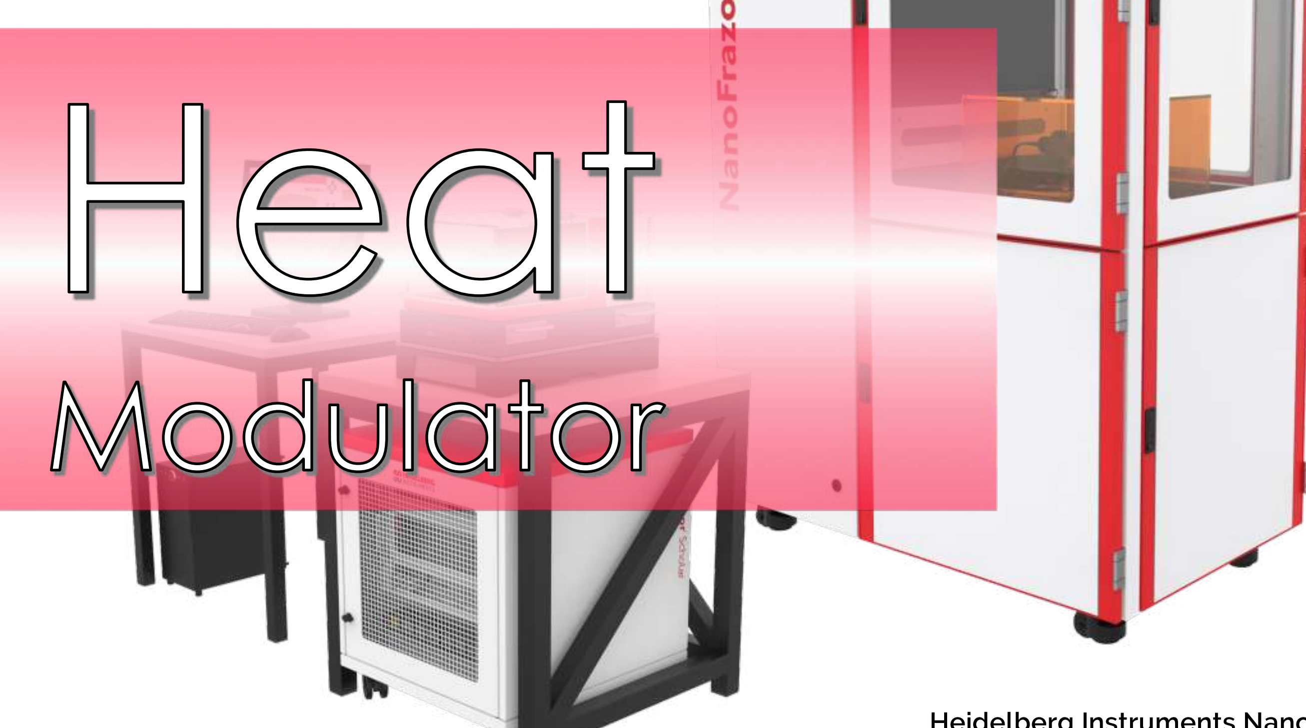
Scale it. Shape it. | Focus on Functional Structures

MPO has developed and optimized processes to produce **basic functional structures** that can be integrated in a variety of components.



NanoFrazor

Heat Modulator



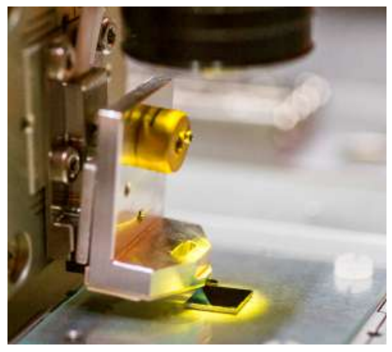
9 March 2022

Heidelberg Instruments Nano SwissLitho AG
Technoparkstrasse 1
8005 Zurich, Switzerland

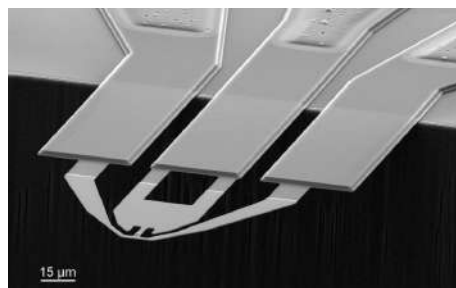
NanoFrazor Thermal Cantilevers

Key features

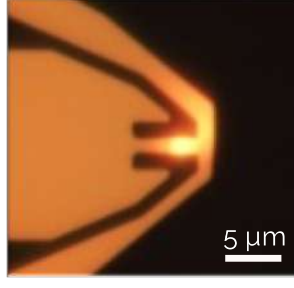
- **Ultra-sharp tip** (silicon)
- **Integrated tip heater** (resistive, up to 1100°C with 1 K resolution)
- **Integrated actuation** (electrostatic for fast and accurate deflection)
- **Integrated topography sensor** (unique AFM mode based on thermal distance sensor)



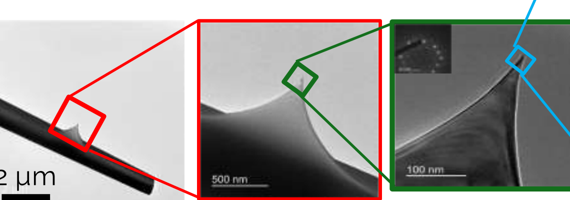
Smart cantilever holder
- Exchange within 1 min
- Access almost any sample



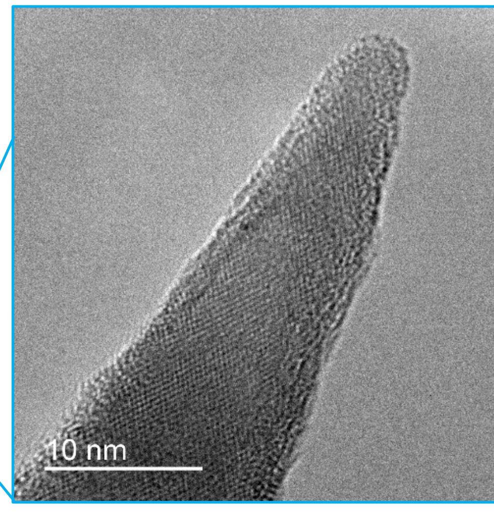
NanoFrazor Cantilever made of Si



Glowing tip heater

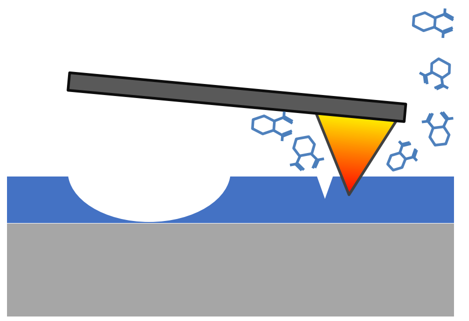


Tip with < 2 nm radius

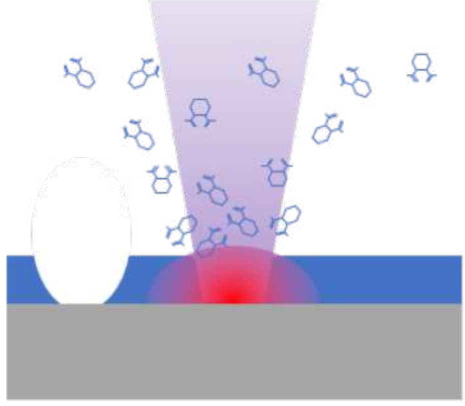


Principle of NanoFrazor

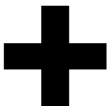
Writing



Thermal probe
- 10 nm sharp tip
- fast and accurate deflection

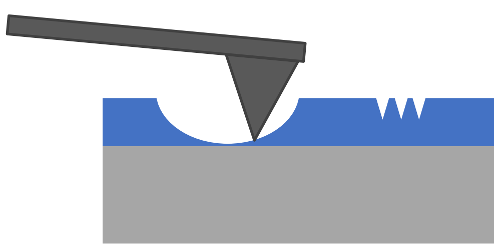


Laser sublimation
- micrometer resolution
- 100x faster



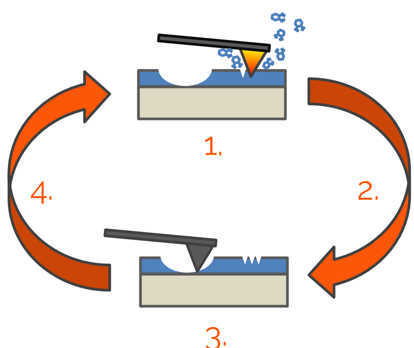
Reading

in-situ high-speed AFM
- Inspection
- Metrology
- Overlay & Stitching



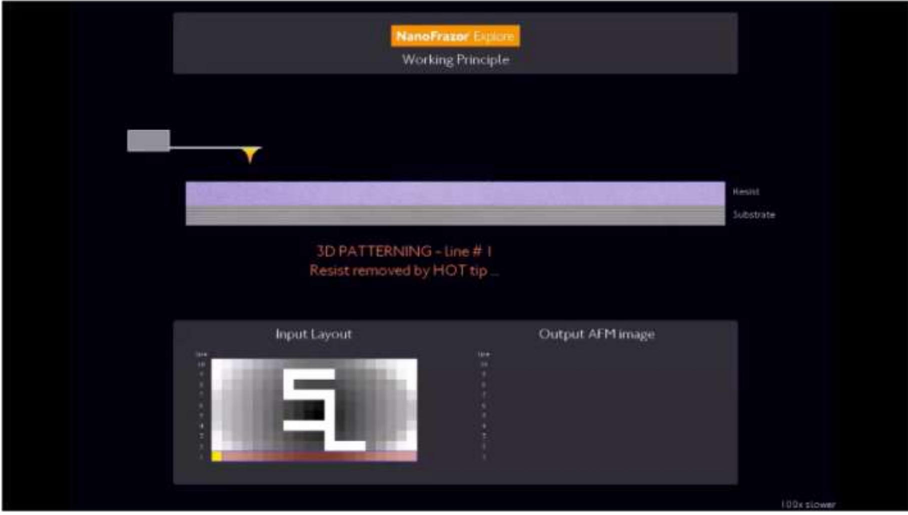
unique distance sensor
- Level plane & Autofocus
- Drift corrections
- Other calibrations

Closed-Loop Lithography: Patterning & Imaging



Every few milliseconds:

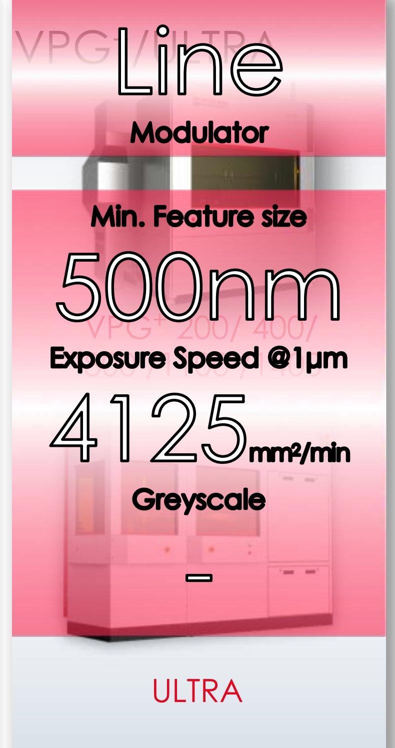
1. Patterning one line with hot tip
2. Cool down tip in few microseconds
3. Image topography of written line
4. Feedback algorithm to adapt patterning
5. Patterning of next line

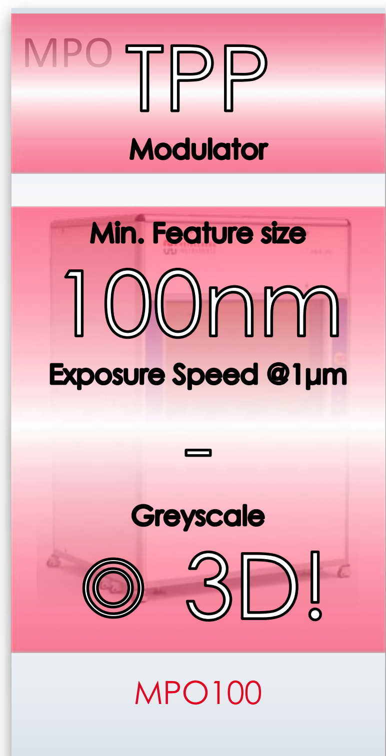


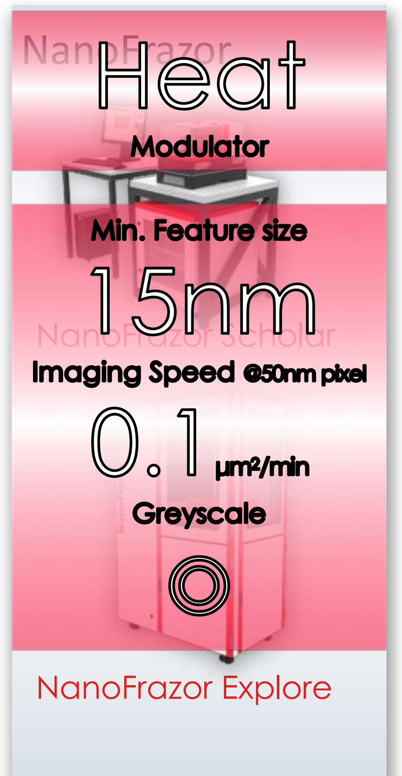
» "What You See Is What You Get"
» No separate metrology necessary after lithography
» Check and online adaption of patterning **every few ms**

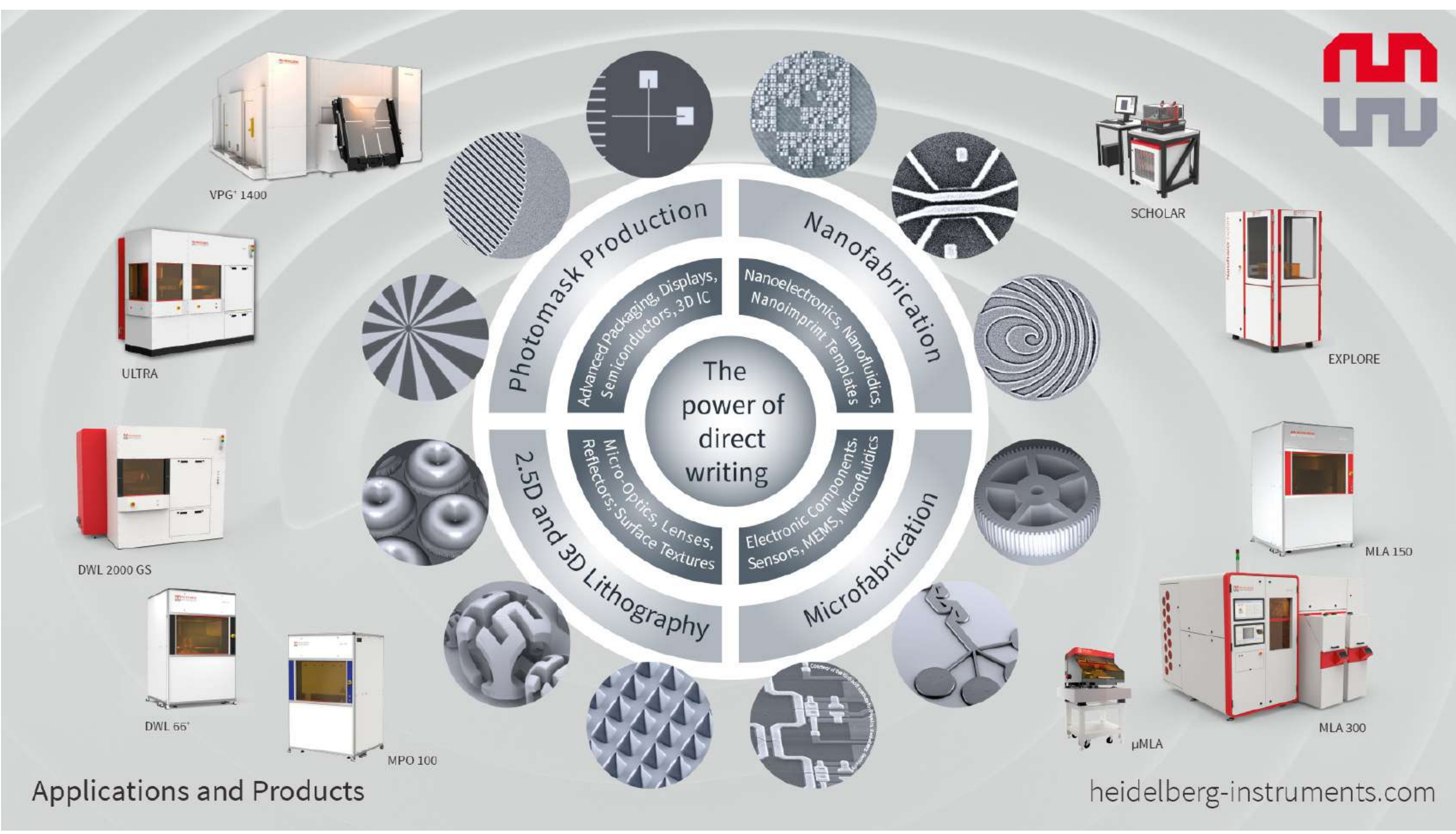
⇒ **Decrease total fabrication time**
⇒ **Increase accuracy and reliability**

Heidelberg Instruments Product Lines Overview



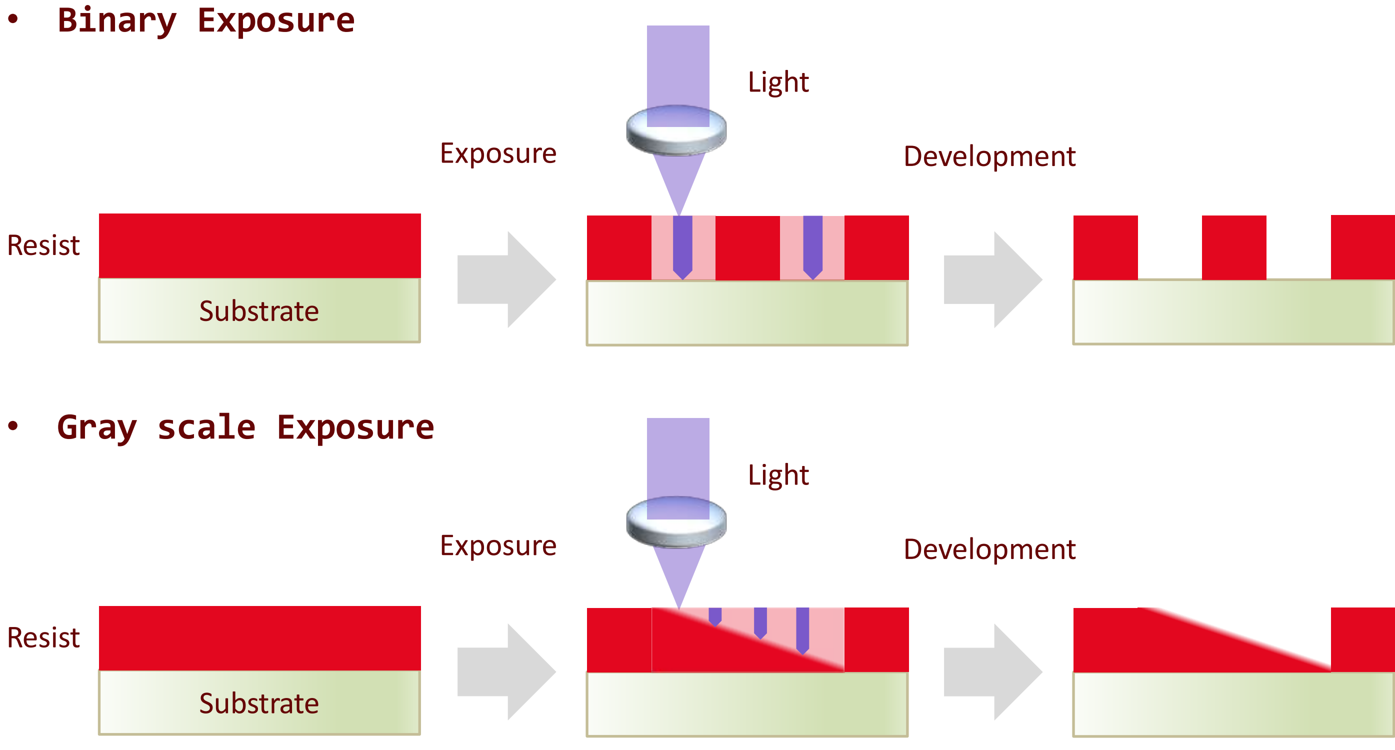




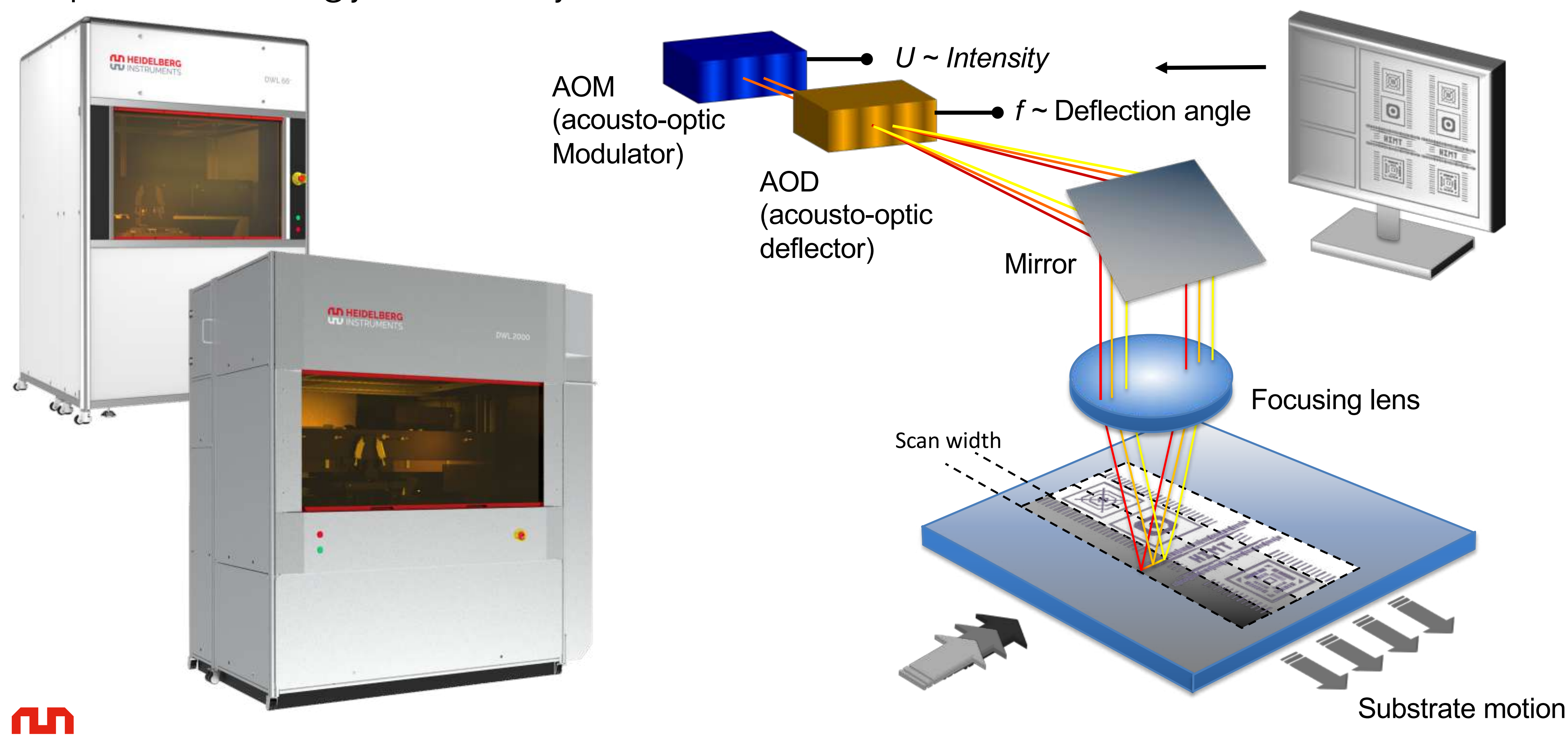


VPG+ 1400
ULTRA
DWL 2000 GS
DWL 66+
MPO 100
SCHOLAR
EXPLORE
MLA 150
MLA 300
µMLA
Photomask Production
Advanced Packaging, Displays, Semiconductors, 3D IC
Nanofabrication
Nanoelectronics, Nanofluidics, Nanoimprint Templates
2.5D and 3D Lithography
Micro-Optics, Lenses, Reflectors; Surface Textures
Microfabrication
Electronic Components, Sensors, MEMS, Microfluidics
The power of direct writing
Applications and Products
heidelberg-instruments.com

The Basic Principle



Exposure strategy in DWL systems



Acousto-optic modulator and deflector

AOM

Acousto-optic deflector

AOD

0. order

1. order

scan

φ

$$\sin\varphi = \frac{\lambda}{2d} = \lambda\frac{f}{2c_s}$$

RF-Voltage

f [MHz]

t [µs]

RF-Voltage

f [MHz]

t [µs]

Acousto-optic modulator

Exposure strategy in DWL systems

AOM

RF-Voltage

U [V]

t [µs]

1. order

Pattern definition

... in design coordinates
(STL, XYZ-ASCII)

(x_1,y_1,z_1)
(x_2,y_2,z_2)
(x_3,y_3,z_3)
z
y
x

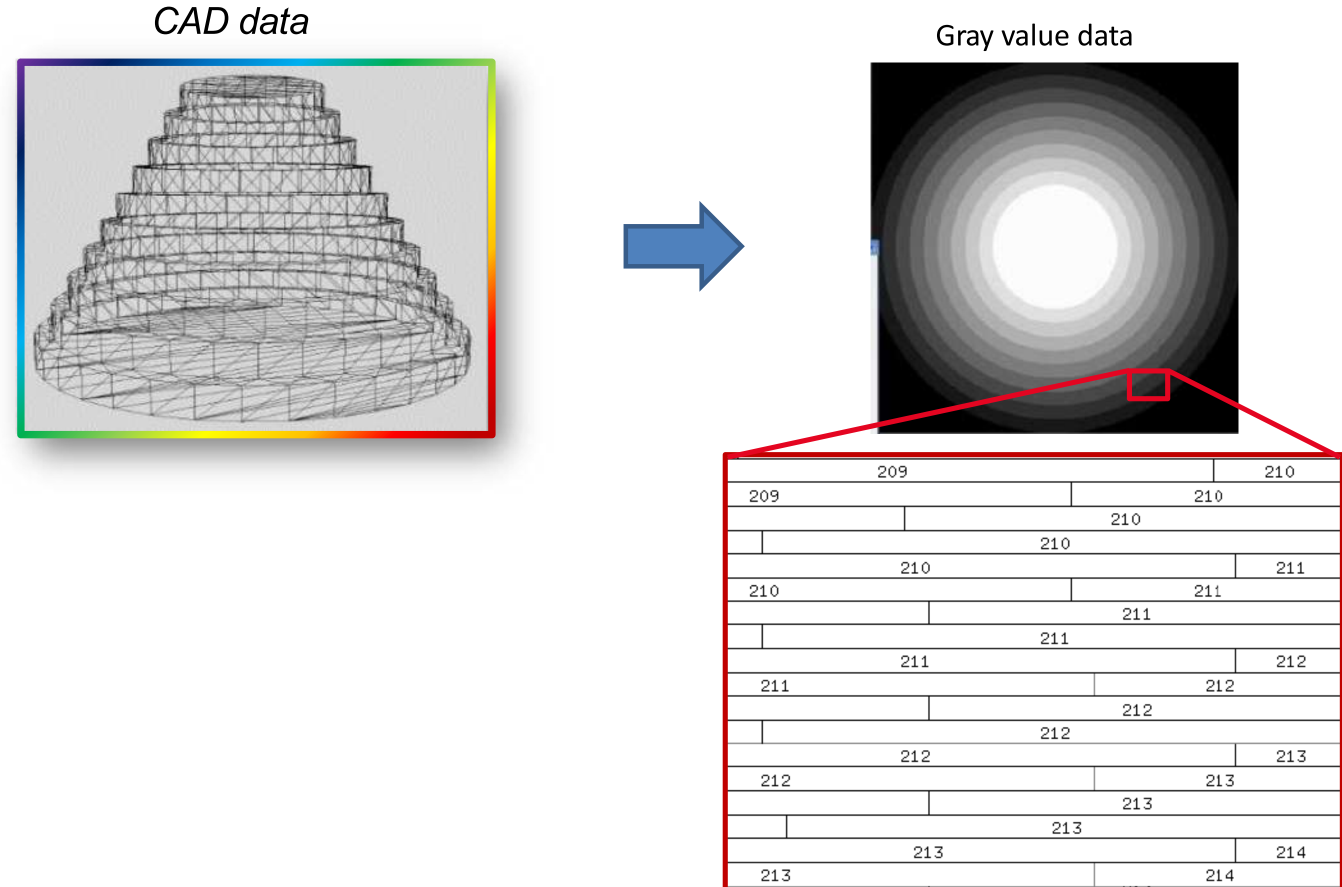
... in bitmap grayvalues
(BMP,PNG)

... in design layers
(DXF)

Layer 0
Layer 1
Layer n

HIMT CONVERSION SOFTWARE

Coordinates (x_i,y_i)	⇔	Exposure Dose GV = {0,1024}


CAD data
Gray value data
209
210
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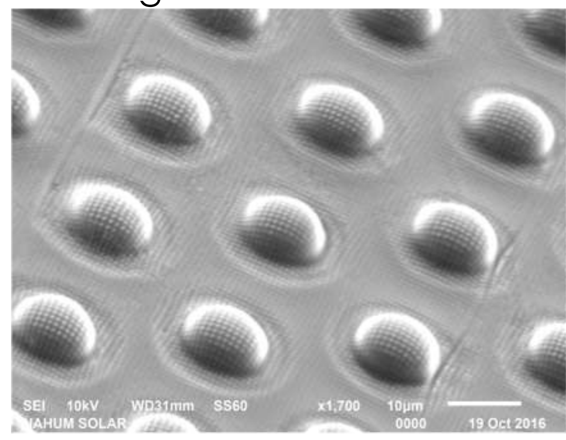
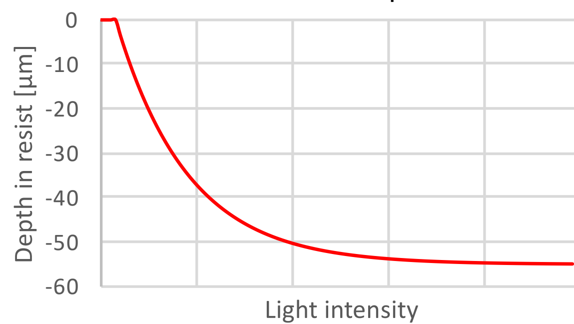
214

Challenges in grayscale lithography…

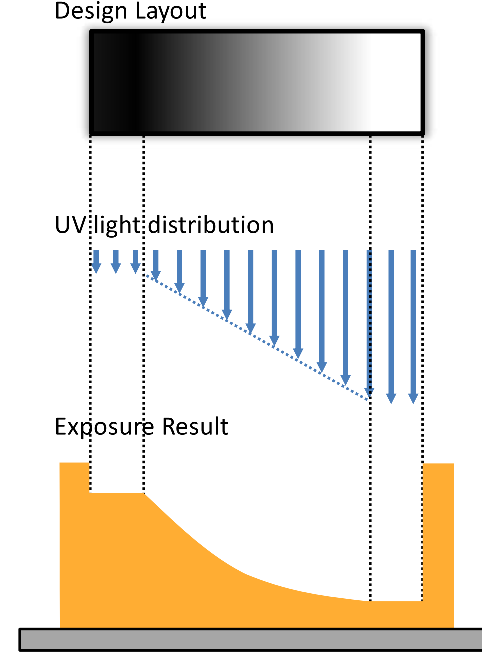
Stitching & other defects



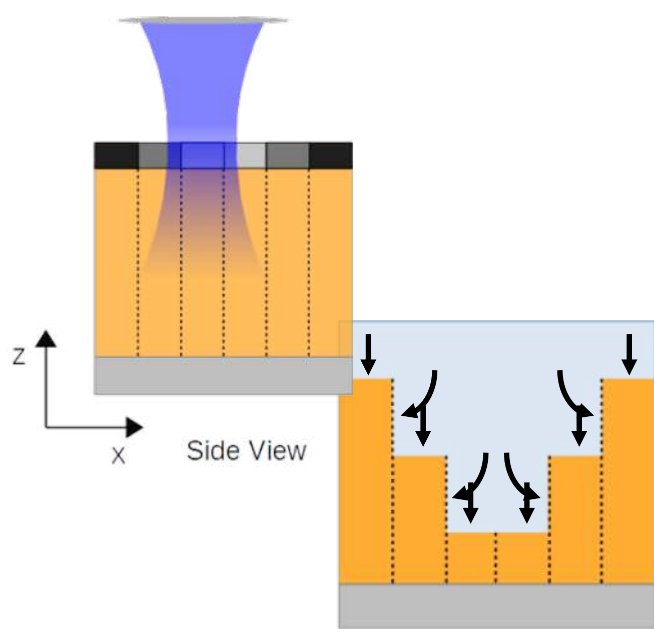
Maximum structure depth



Resist non-linearity

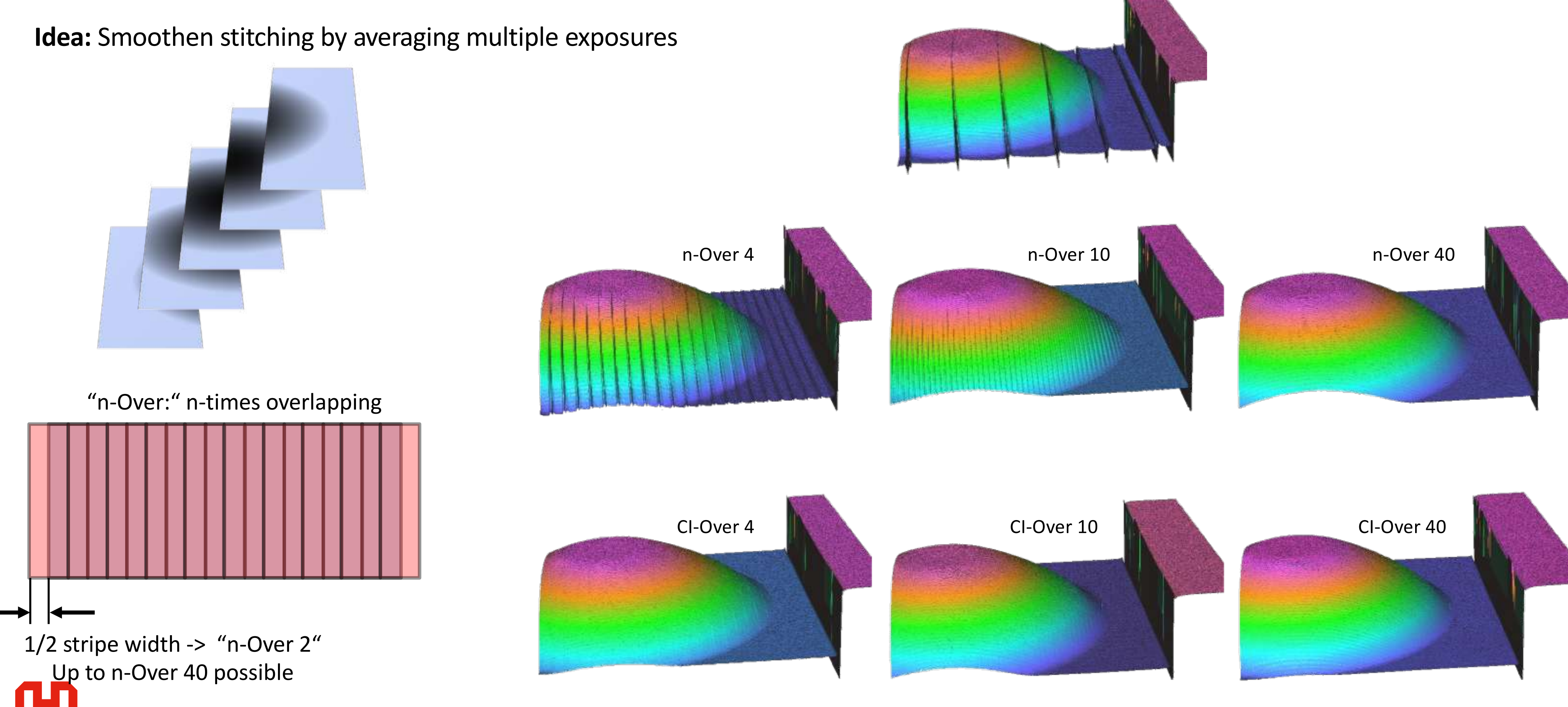


Proximity & process effects

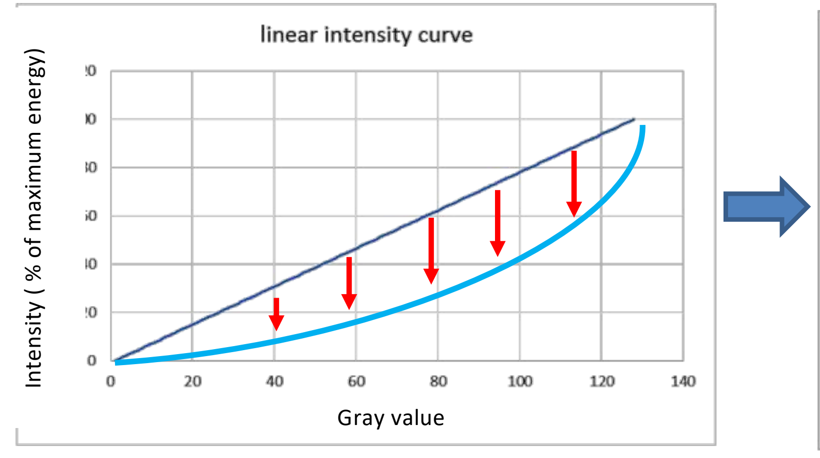


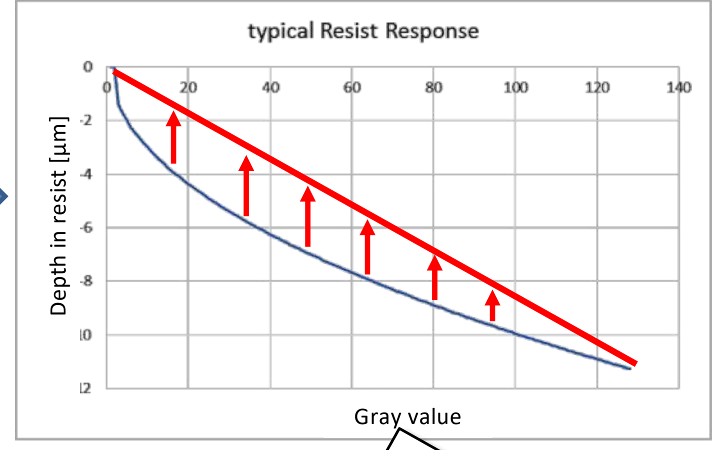
… and our solutions

Stitching optimization



Shape Optimization:Linearization





- Resist does not respond linearly
  - Minimum energy needed for photoreaction
  - Exposure proximity effect
  - Lateral development effect

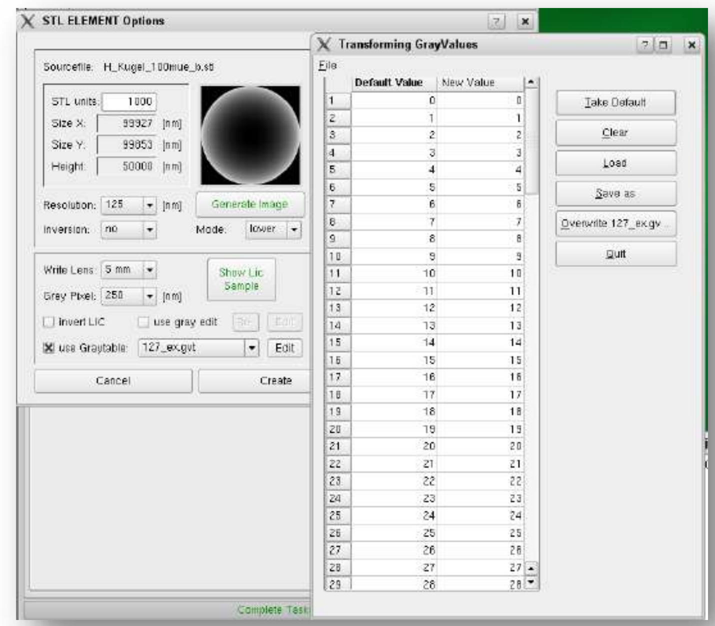
→ Geometry dependent

Without linearization

Measured
Target
Z [µm]
X [µm]

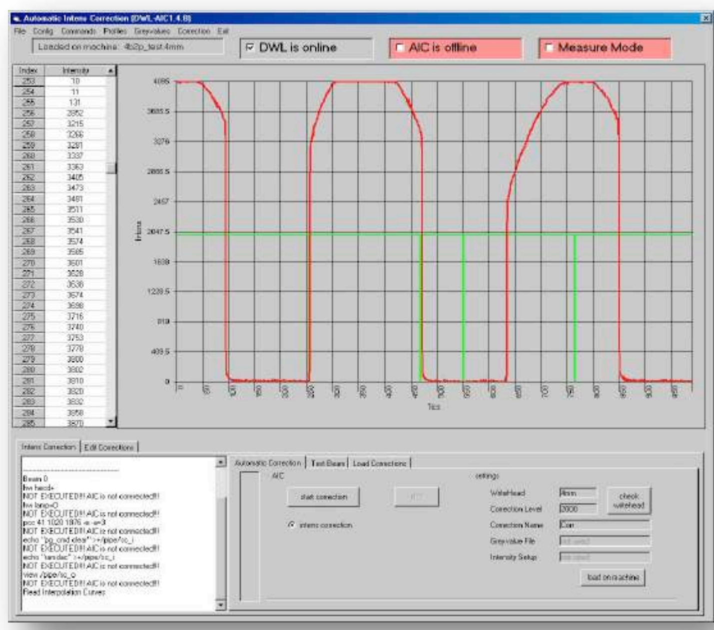
GRAY SCALE OPTIMIZATION METHODS

Gray Value Table (GVT)



- Maps design gray value to customized gray value
- Transformation at conversion level
- Decrease of gray level resolution

Automatic Intensity Correction(AIC)

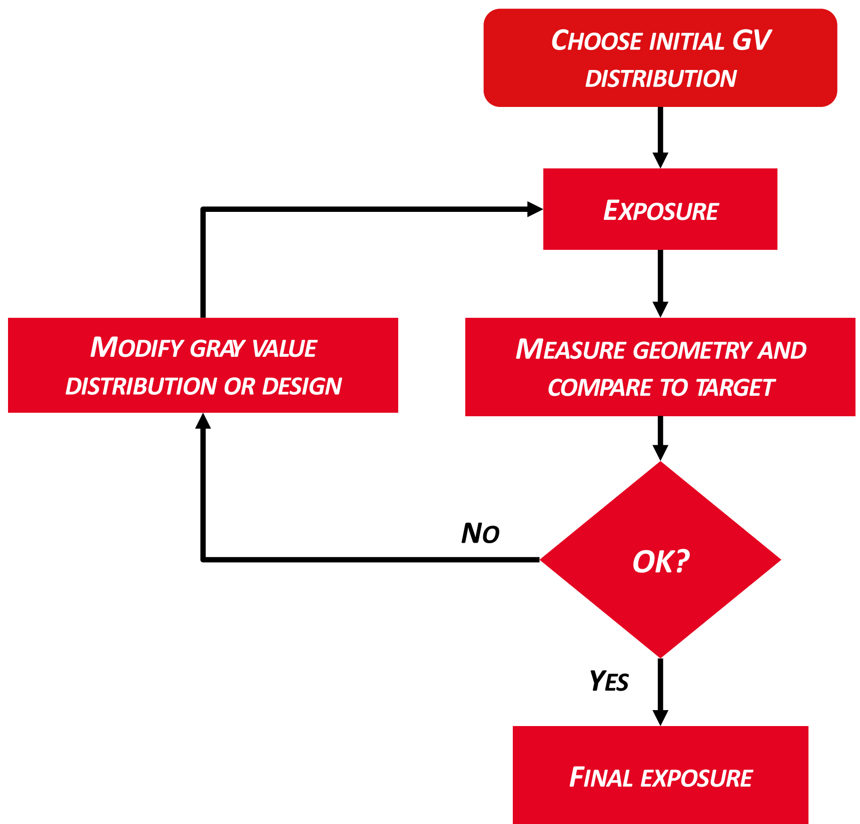


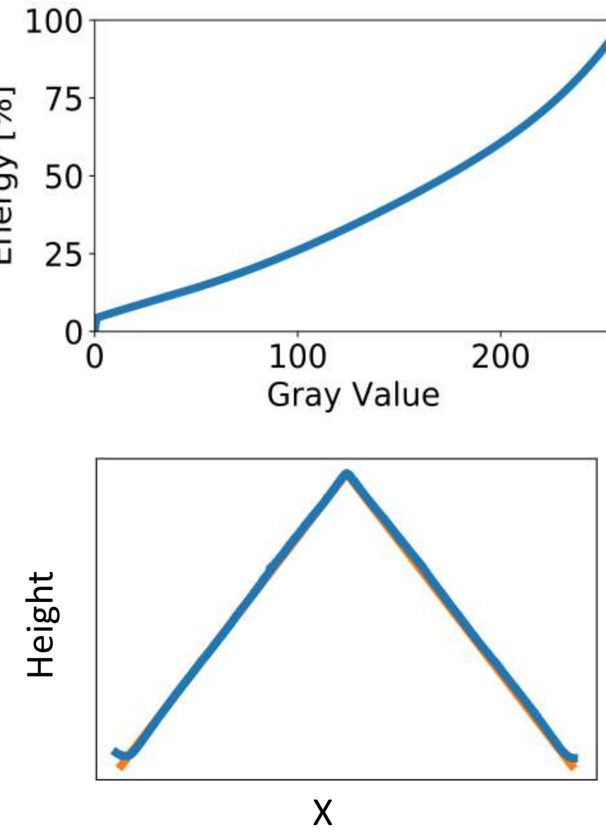
- Assigns design gray value to energy level
- Transformation at exposure level
- Keeps gray level resolution

Shape Optimization:Linearization

- Use of a non-linear relation between GV and energy:
  - One of 65000 energy levels can be assigned to each grayvalue

Non-linearity & proximity effects
GVD approach





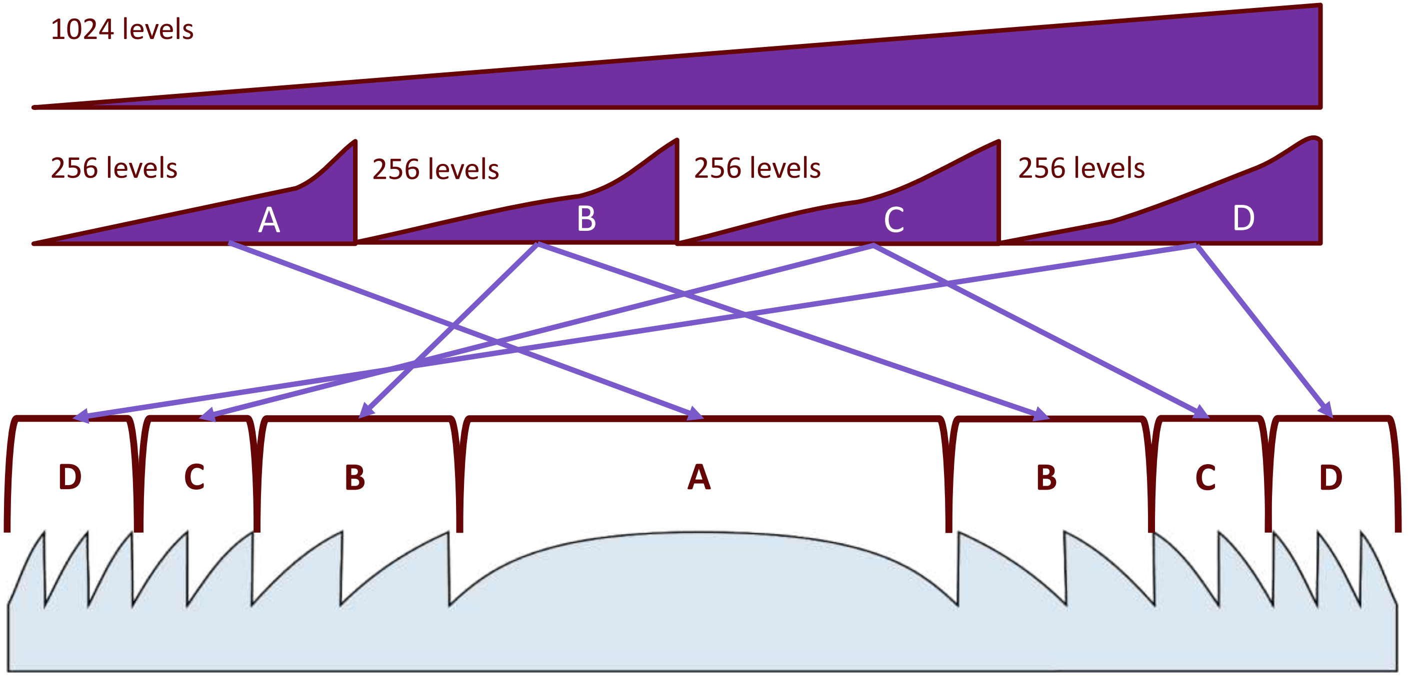
Why we need 1024 Grey Levels

A

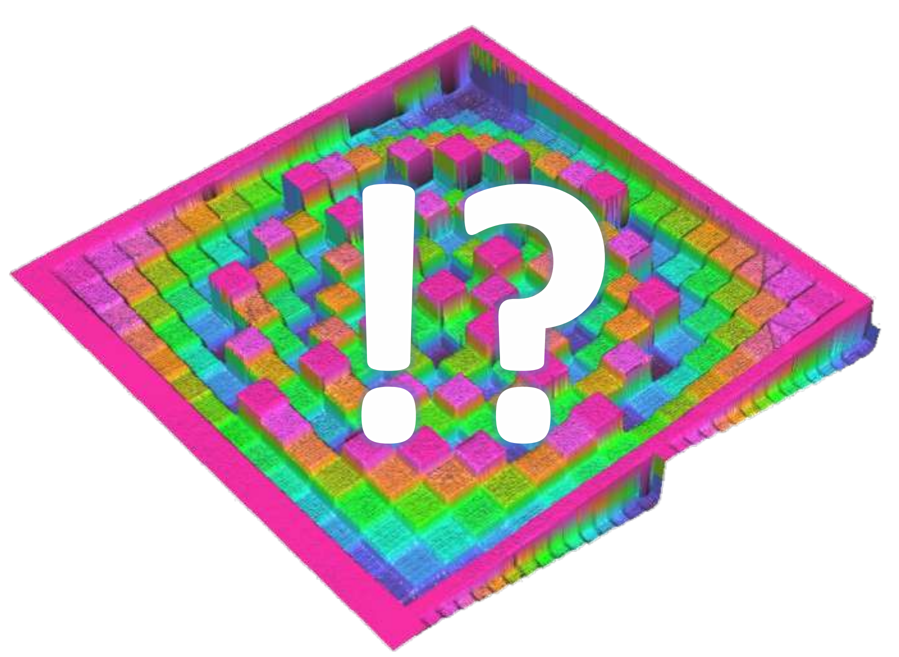
B

!?

Why we need 1024 Grey Levels



!



Non-linearity & proximity effects
GVD approach

Works quite well, but…

- … can be very time consuming
- … requires compromises
- … fails for irregular designs

Courtesy of IGI

Target Cross Section

Top view

Hexagonal microlens array

Positions with same theoretical depth, but different local environment

⇒ Same dose assignment leads to different resulting depth!

Non-linearity & proximity effects
BEAMER 3D-PEC

Layer Properties

Layer	Height [um]	rel. Height
1	9.0	0.947
2	8.968503937	0.944
3	8.937007874	0.941
4	8.905511811	0.937
5	8.874015748	0.934
	8.842519685	0.931
	8.811023622	0.927

Pattern data
gds, dxf, png, oasis, bmp

Tool
Spot size, gray values

Process
Resist data, contrast curve

BEAMER
3D-PEC

Exposure pattern
png, bmp, HIMT

z
x
Side View

Remaining Resist Height [µm]
10
8
6
4
2
0
0
50
100
150
200
250
Gray Value

Non-linearity & proximity effects BEAMER 3D-PEC

GenISys

Example: DOE

BEAMER

Remaining Resist Height [µm]

Gray Value

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