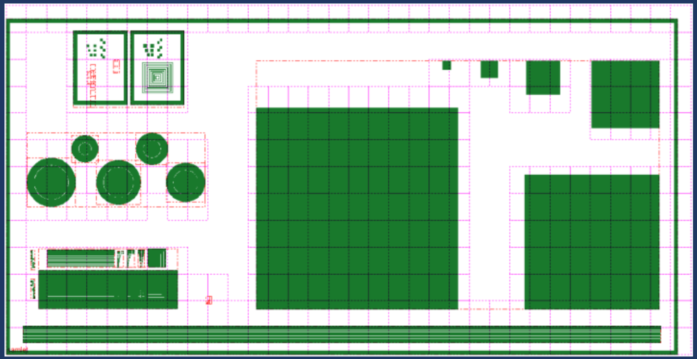
Introduction to maskless UV-lithography

BASIC tutorial

NNUM 2019
DTU Denmark



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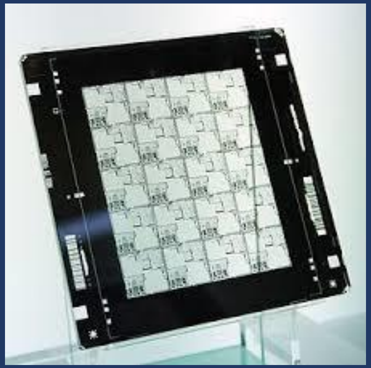

https://en.wikipedia.org/wiki/Photomask

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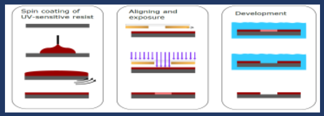
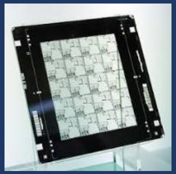
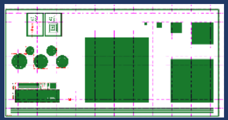
Lean Pedersen

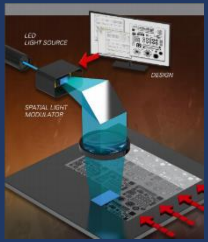
Agenda

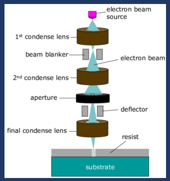
- Lithography overview
- Differences in mask lithography and maskLESS lithography
- Several different maskless lithography techniques introduced.
- Pros and cons of different methods
- Heidelberg tools from the maskless series (MLA100 and 150).
- Process examples
- Other facility's and maskless tools

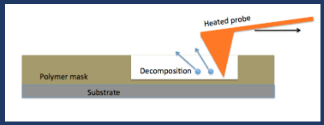


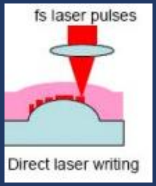


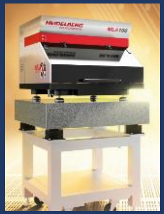


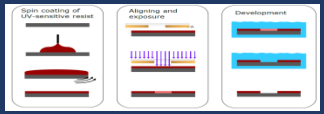




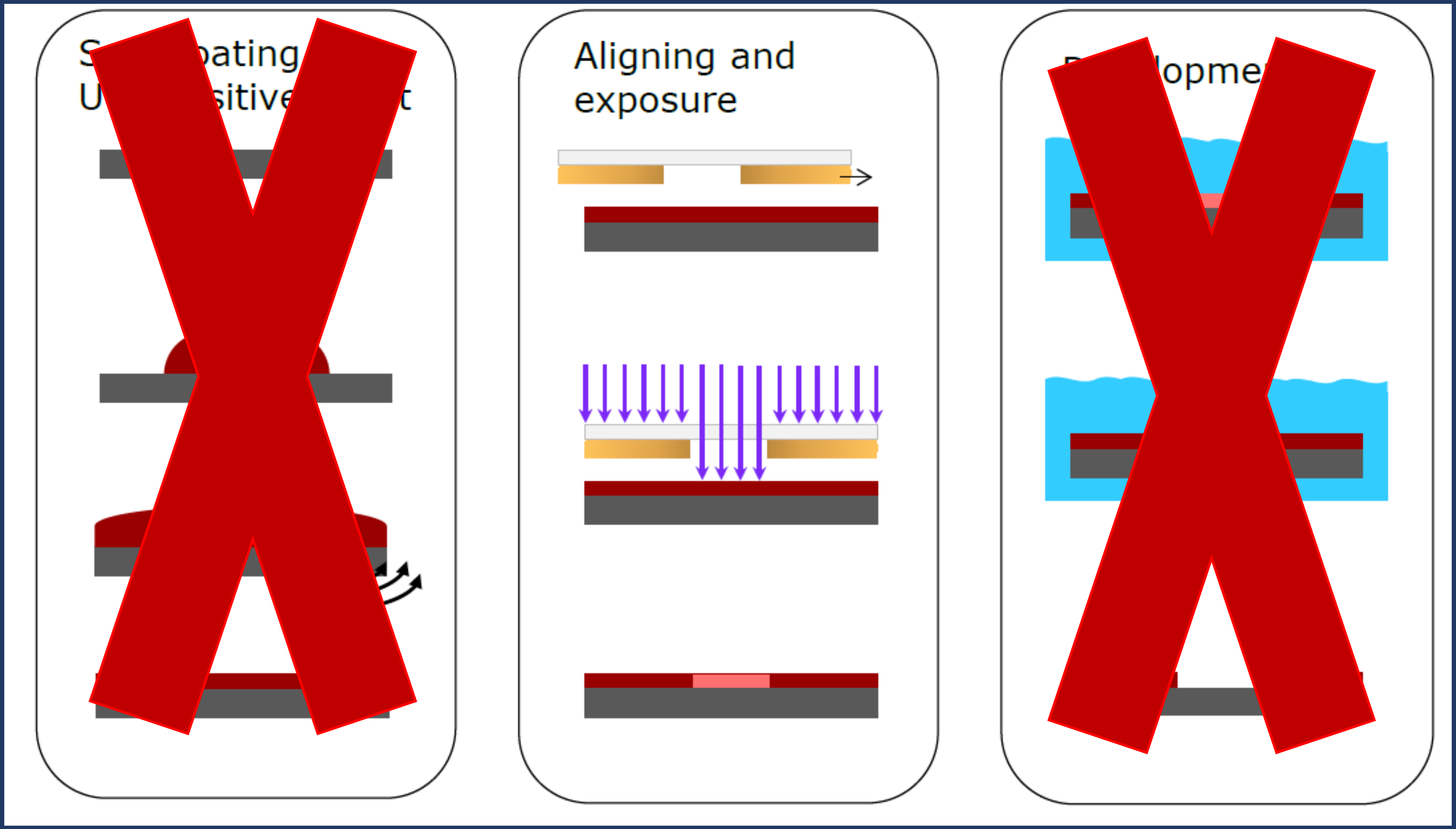








General lithography steps



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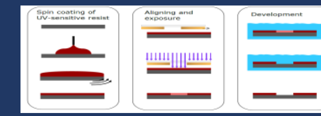


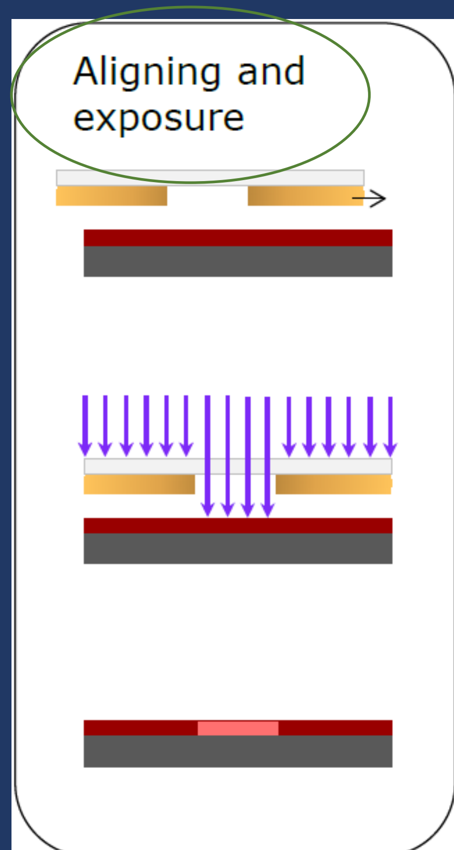
Lithography scope

Alignment:

First print (no alignment)
or
Alignment (atleast 1 step of alignment)

”Exposure”:

Different ways of patterning the ”resist”
Eg.
E-beam, (E/D)UV, Imprint, probe etc.



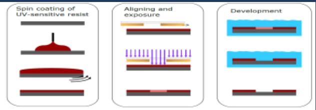
Pattern transfer:

Direct patterning
eg. Laser, FIB SEM
Or
2 step incl. ”resist”

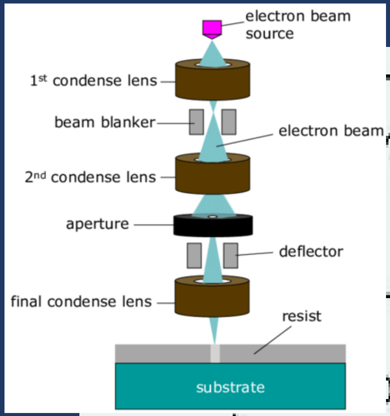
Tone/inverted:

Patterns can transfer 1:1 or inverted

Positive and negative tone resist



“Exposure” modes



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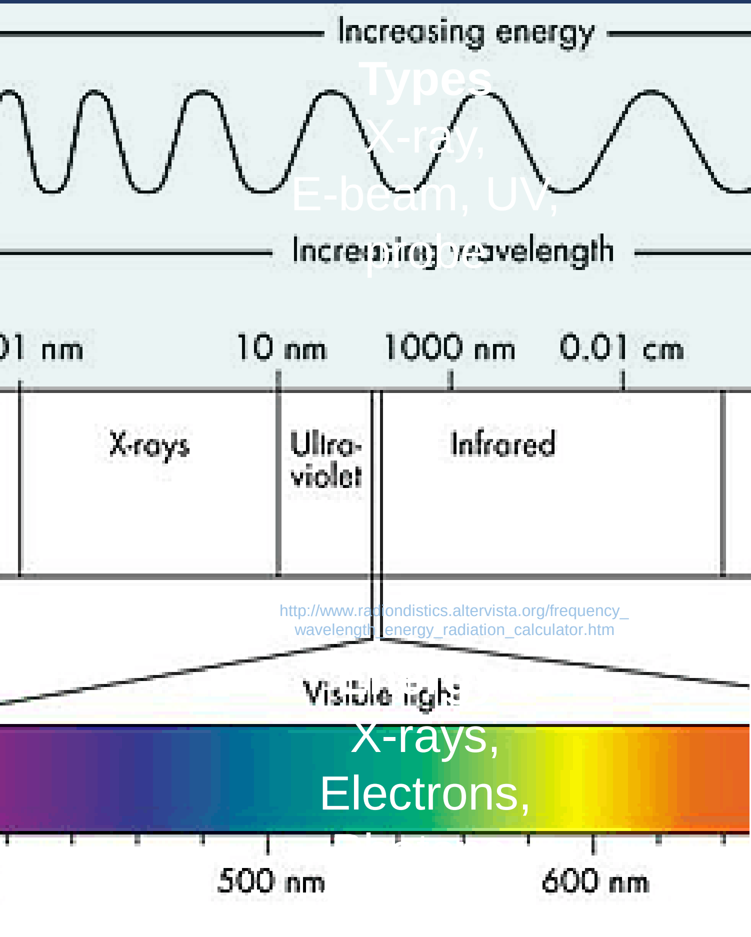
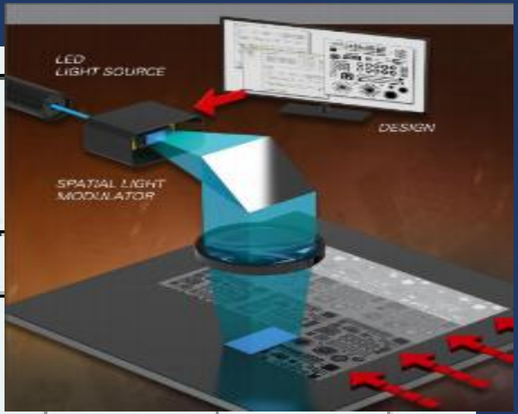


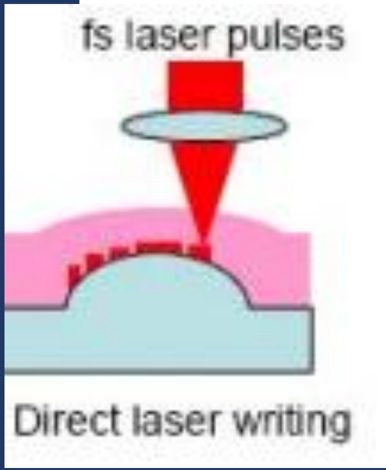
Types
X-ray,
E-beam, UV,
probe



https://www.himt.de/files/Factsheet%20Download/HIMT_Fact%20Sheet_MLA100_2017_Web.pdf

http://www.radiondistics.altervista.org/frequency_wavelength_energy_radiation_calculator.htm

X-rays,
Electrons,



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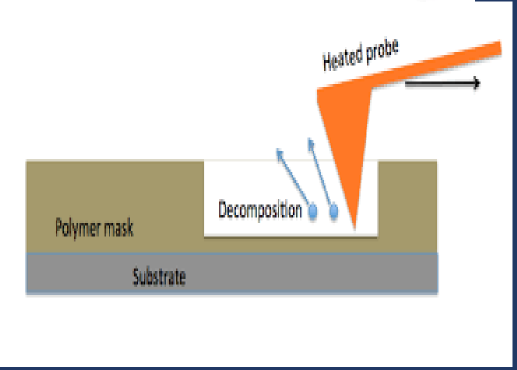
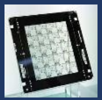


https://en.wikipedia.org/wiki/Thermal_scanning_probe_lithography

”Chemical”



Mask vs. maskless

- Same results
- Different ways of exposing

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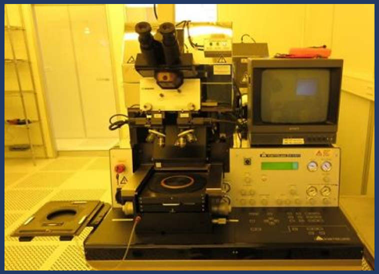
Mask Aligners	MaskLESS Aligners
Pattern replicator	Pattern generator
Need physical mask	Need ONLY design
Long time for design change	Instant design change
Mask can be contaminated/damaged	Electronic file need specific format
”Exposure” time is short – good for batch processing	Exposure time often longer
Often cheaper to aquire	Often expensive



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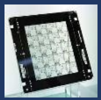
https://www.himt.de/files/Factsheet%20Download/MLA150%20fact%20sheet%202018.pdf



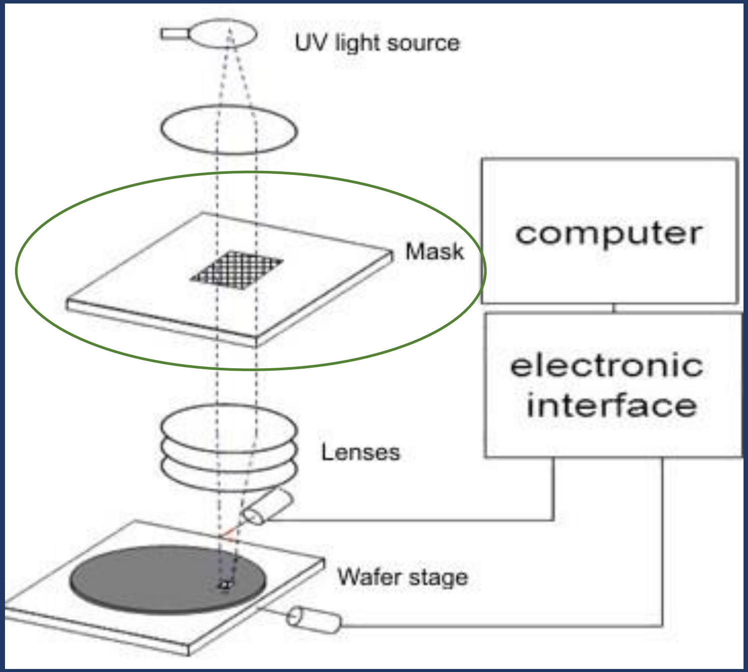
Masked lithography

- An **mask** aligner is a pattern **REPLICATOR**

\+ Chip pattern defined in the mask, can be repeated FAST

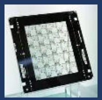
\+ Throughput is measured in "*wafers per hour*"

− Pattern changes require lead time to implement (a new maskset)



Adapted from Bengt Nilsson
Chalmers University of Technology

Masked



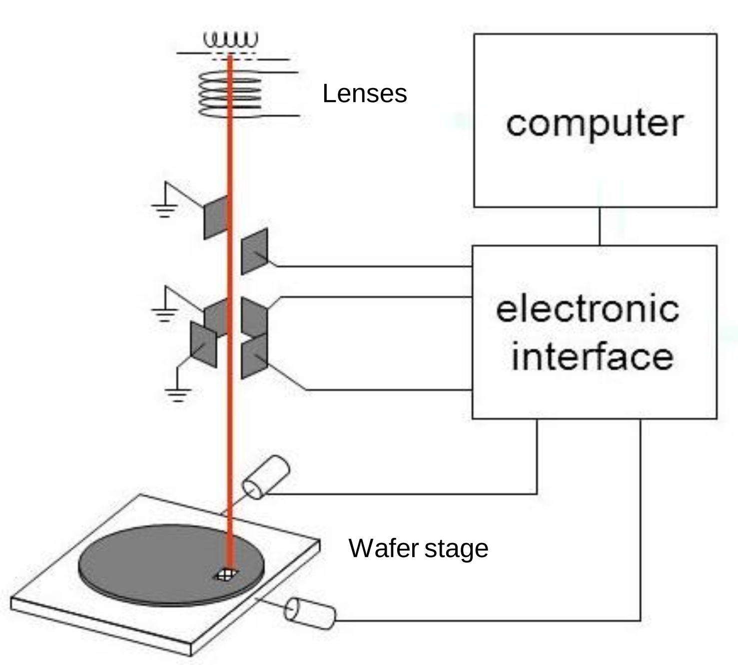
MaskLESS lithography

- A **maskless tool** is a pattern **GENERATOR**
  - Can be **(D/E)UV, E-beam, probe** etc.

+ Pattern modifications can be **implemented immediately**

− Every chip need to be built during exposure, a **SLOW** process

− Throughput is often way smaller, Can be measured in ”*hours per wafer*”



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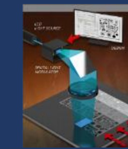
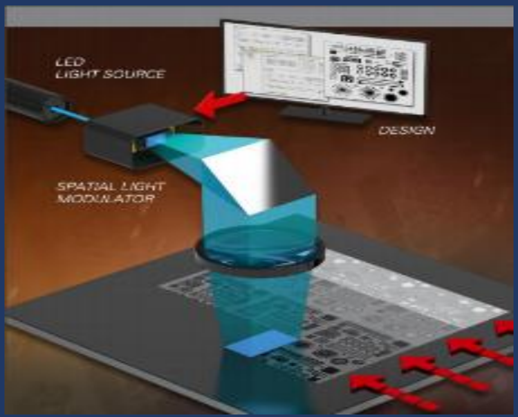
Maskless



MaskLESS UV

- Maskless UV exposure sources
  - LED, Laser, Arc-lamp etc.
- Have a light modulator module
  - DMD, rolling, scanning etc.
- Often optical with lenses
- Exposes fields/lines of design and step
- Design is transfered 1:1 or digitally modified



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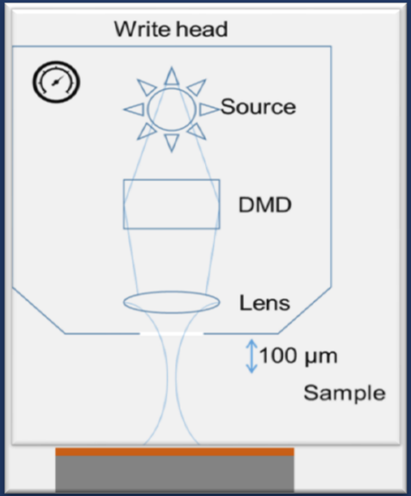

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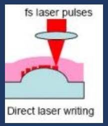
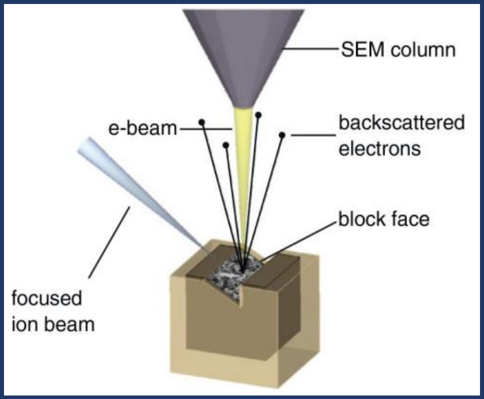
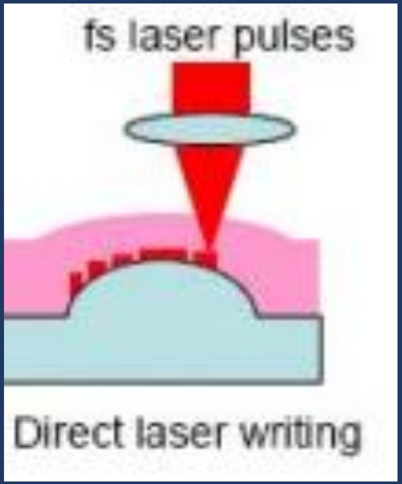


MaskLESS direct writing

- Direct writing can mean:
  - Direct pattern transfer as FIB/SEM
  - Or High power laser cutters
- Direct laser writting is a 2 step process with photosensitive resist
- Writes single pixel at a time in a raster pattern – slow process
- Can pattern structured surfaces



https://www.embl.de/services/core_facilities/em/services/fibsem/



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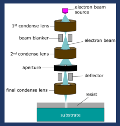

MaskLESS E-beam

- E-beam writers expose with electrons
- Electron sensitive resist needed
- Small feature size of few nm
- Dedicated systems – large, expensive and complex
- Rasterscans each voxel-field
  - Exposure time very long – hours pr. wafer
- Subject to Proximity effects

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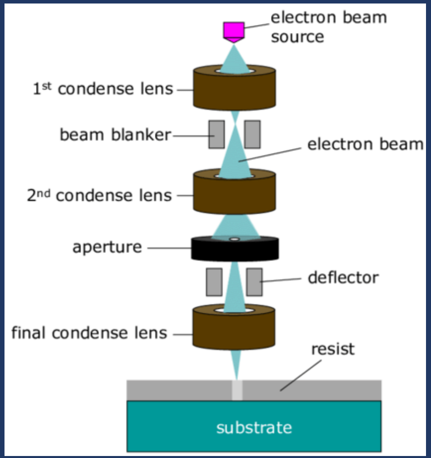

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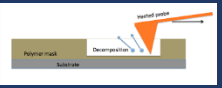
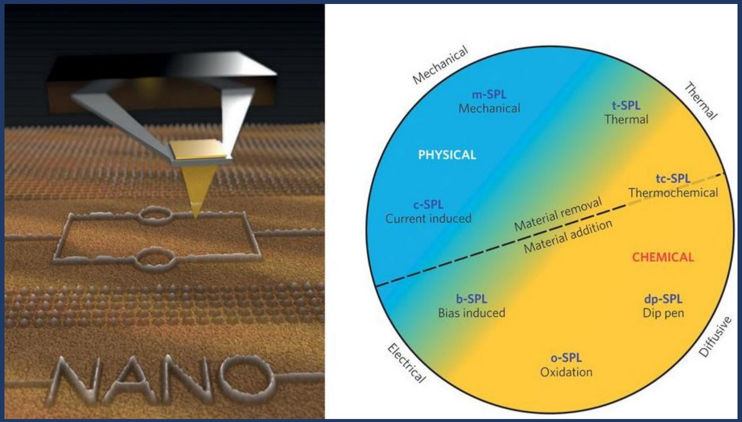
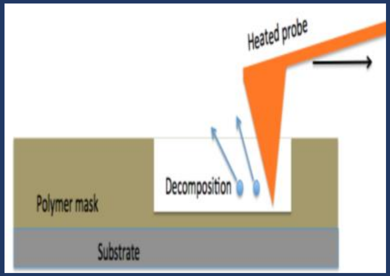


MaskLESS probe

- Probe lithography uses a sharp probe/tip
- AFM Cantilever modulated:
  - Force, Temp., Chemical, electrical
- Either material removal or deposition
- Limited by trigonometry and depth
- Special materials needed



https://www.nature.com/articles/nnano.2014.157



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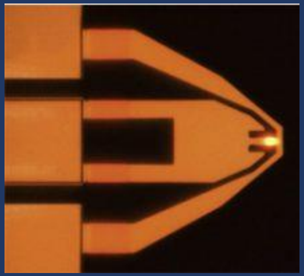
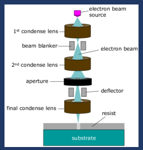
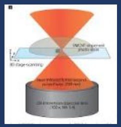
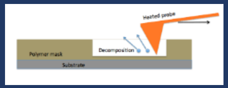


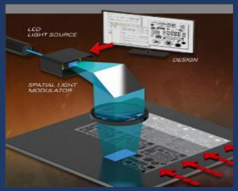
https://swisslitho.com/event/3rd-thermal-probe-workshop/

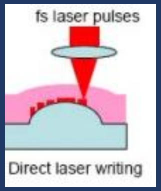


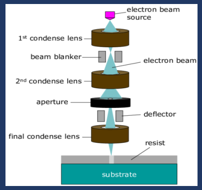


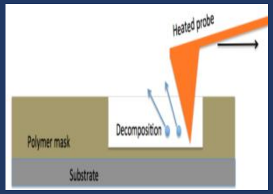


Pros and Cons

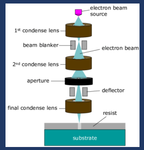








Parameter\Method	UV maskless	Direct laser writing	E-beam	Probe lithography
Resolution	Sub µm~ 0.5µm	Sub µm~ 0.25µm	Few nm	10+ nm



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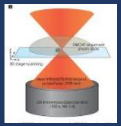

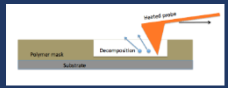

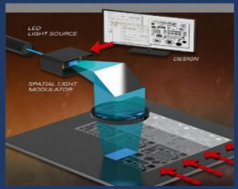

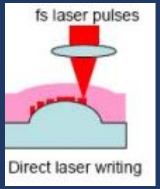

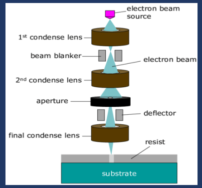

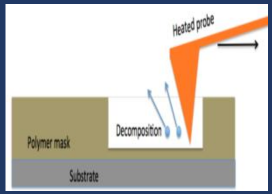

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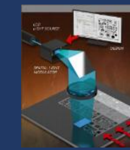
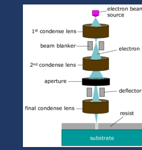
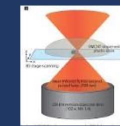
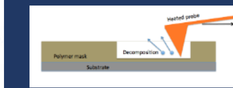
Resolution	Sub µm~ 0.5µm	Sub µm~ 0.25µm	Few nm	10+ nm
Speed mm^2/min	50mm^2 – 1100 mm^2	90mm^2 – 2000 mm^2	1E^{-4} mm^2 – 0.6 mm^2	1E^{-5} mm^2 – 3E^{-5} mm^2

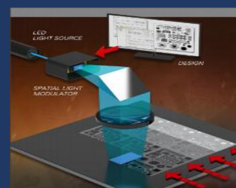


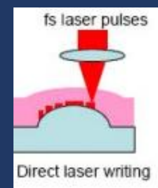


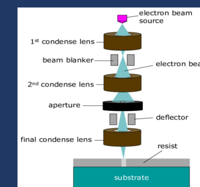


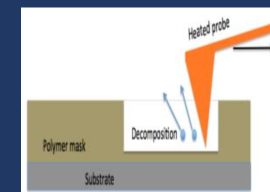


Pros and Cons









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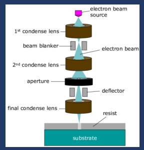
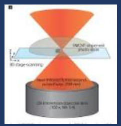
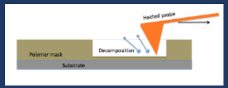
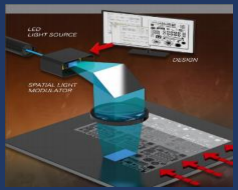
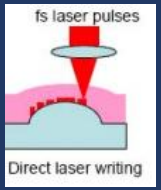
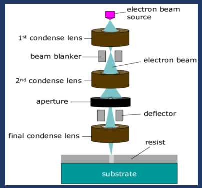
Resolution	Sub µm~ 0.5µm	Sub µm~ 0.25µm	Few nm	10+ nm
Speed mm^2/min	$50 mm^2$ – $1100 mm^2$	$90 mm^2$ – $2000 mm^2$	$1E^{-4} mm^2$ – $0.6 mm^2$	$1E^{-5} mm^2$ – $3E^{-5} mm^2$
Complexity	Little to very	Little to very	Very complex	Simple

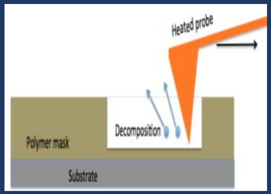





Pros and Cons









Parameter\Method	UV maskless	Direct laser writing	E-beam	Probe lithography
Resolution	Sub µm~ 0.5µm	Sub µm~ 0.25µm	Few nm	10+ nm
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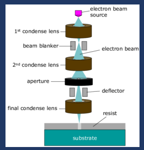
Complexity	Little to very	Little to very	Very complex	Simple
Cost	Cheap - expensive	Middle - expensive	Expensive	Cheap - expensive



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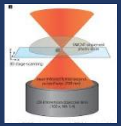

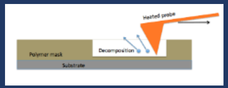

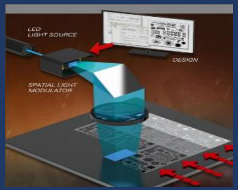

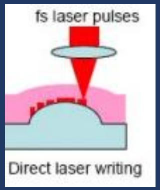

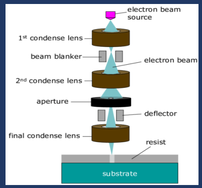

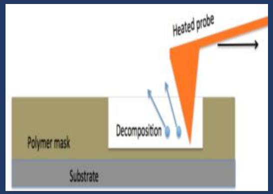

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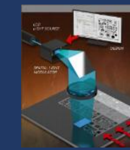
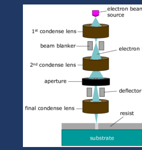
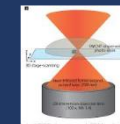
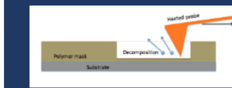
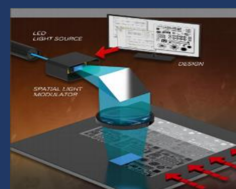
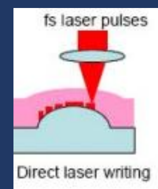
Issues	Data transfer	Beam formfactor	Proximity effect	Only thin resist

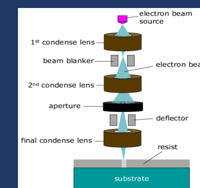



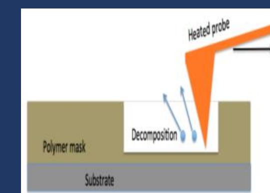
Pros and Cons









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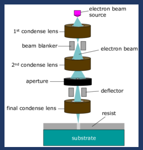
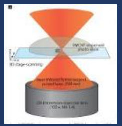
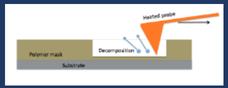
Cost	Cheap - expensive	Middle - expensive	Expensive	Cheap - expensive
Issues	Data transfer	Beam formfactor	Proximity effect	Only thin resist
Benefits	Rotate design	Structured surfaces	Variable speed	View/write, 3D

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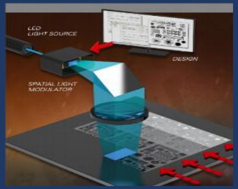

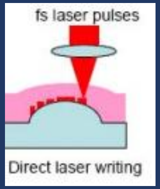

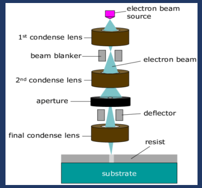

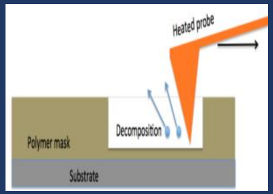

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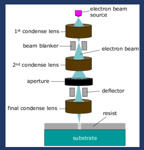
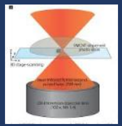
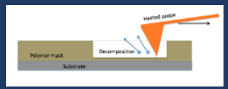
Issues	Data transfer	Beam formfactor	Proximity effect	Only thin resist
Benefits	Rotate design	Structured surfaces	Variable speed	View/write, 3D
Special	Backside alignment	Flexible	e- resist	Therm./chem./elec.



Considerations



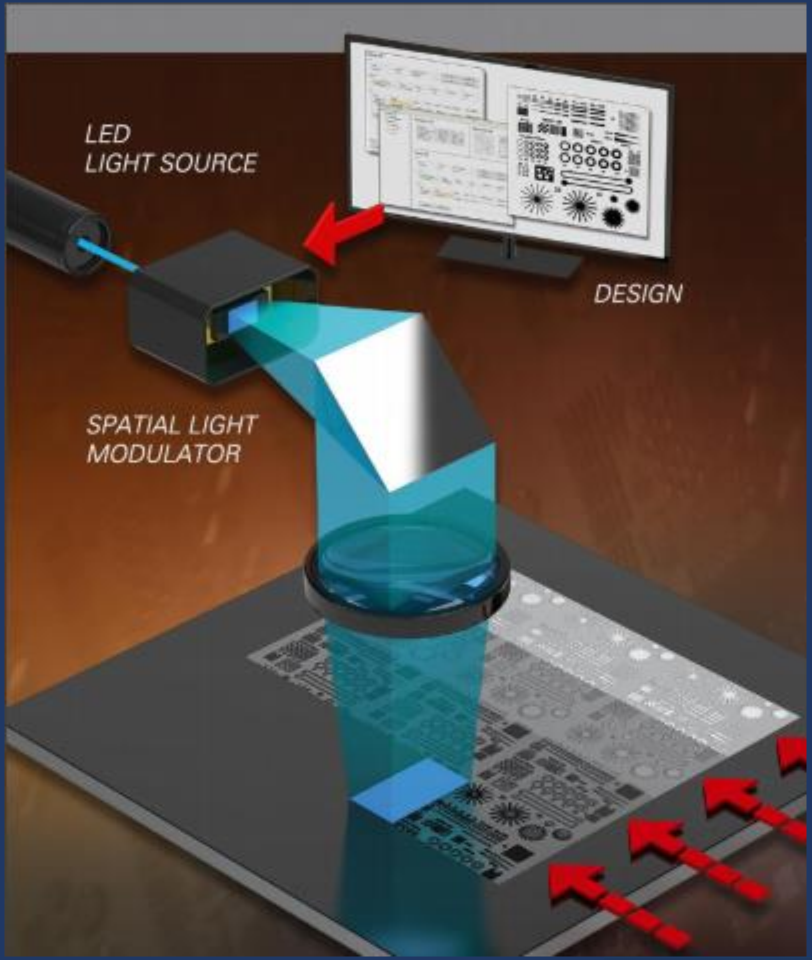


- Alignment accuracy
- Position accuracy
- Drift
- Field/Pixel size
- Preparation
- Time overhead

- Manufacturer
- Maintenance
- Accessoires
- Special features
- Know how
- Learning curve


Exposure principle

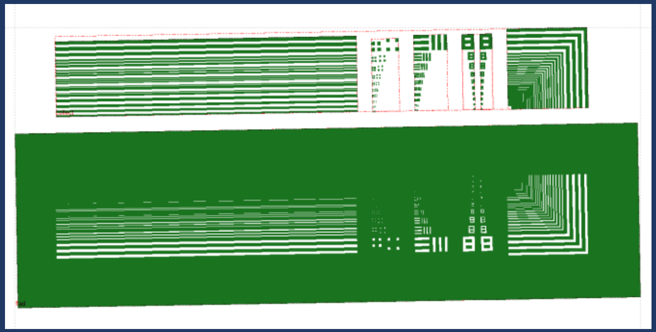
- The sample sits on a stage that moves in X and Y
- The pattern (design) is loaded digitally into the Digital Mirror Device
- A light source illuminates the DMD
- A lens focusses the image onto the surface of the sample
- The exposure field steps across the sample



https://www.himt.de/files/Factsheet%20Download/HIMT_Fact%20Sheet_MLA100_2017_Web.pdf


Exposure principle

- Design updated for every exposure
- Follows the surface (auto-focus)
- Rotation is digital (no θ-stage)
- Gray-scale lithography is possible
- Dose is determined by the ”on-time” of the mirrors in the DMD
- Stitching is smoothed out by overlapping exposure fields



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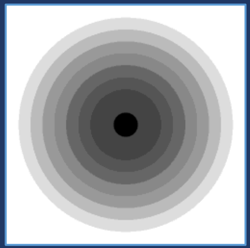
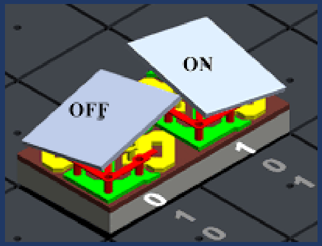


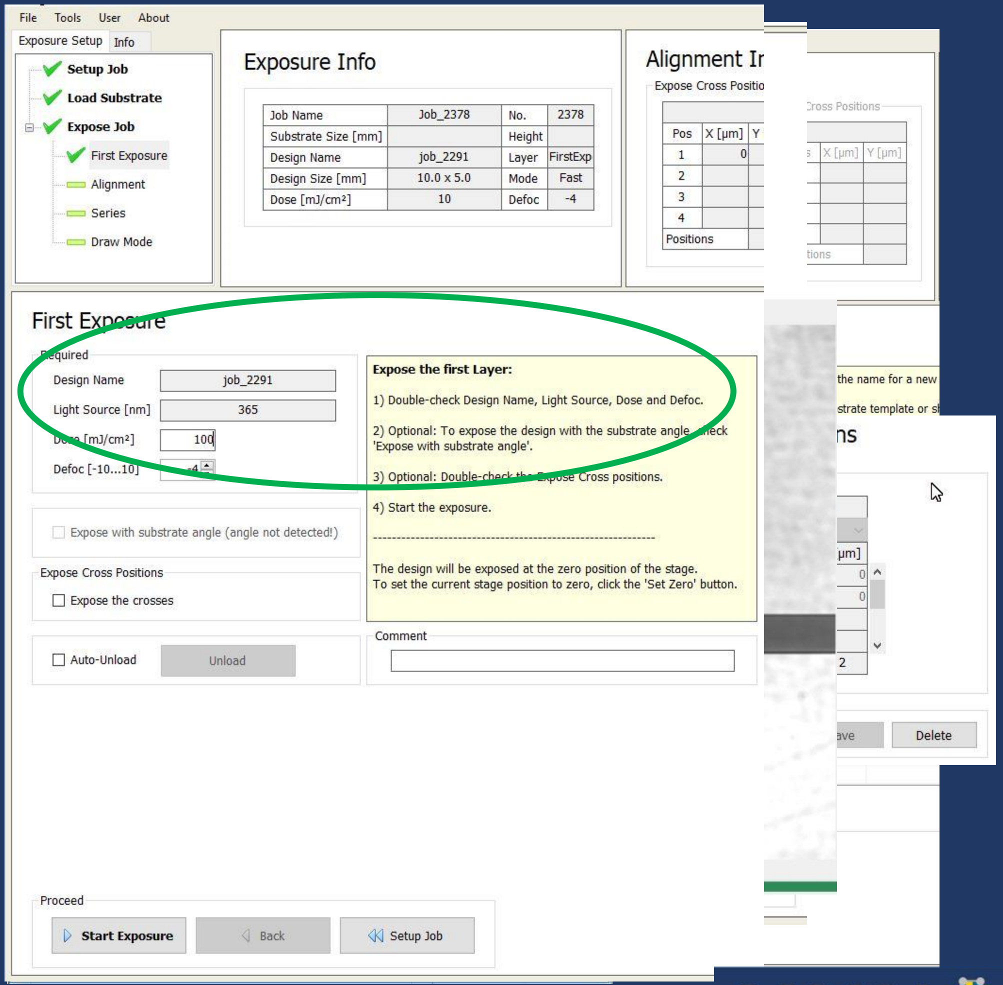
DTU Nanolab Thomas Anhøj



https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6774433

Typical exposure session

- Set up the job
  - Exposure mode
    - First print / alignment
    - Series (dose/defocus test)
    - Draw mode (no CAD)
  - Substrate template
  - Convert design
    - Source file
    - Positioning
    - Exposure options
  - (Alignment mark positions)
- Load substrate (NB: 90°)
- (Align to the marks)
- Set dose and defocus
- Start exposure



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Performance: Sample positioning

Centring

- During sample load, the edges of the sample are detected
- Accurate size and position detected

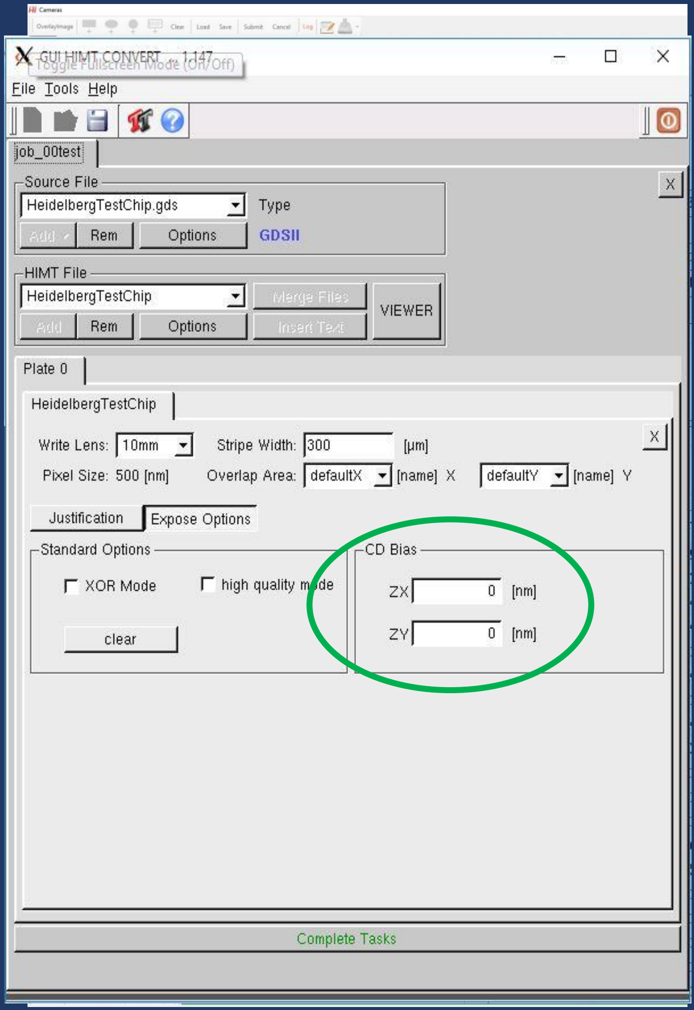
- **Flat alignment**
- During sample load, the angle of the bottom edge/flat is also measured
- This angle can be included in the exposure
- On 4” wafers, the flat alignment accuracy can be down to 0±0.1°

Overlay

- Exposed layer 1 and layer 2 consecutively without unloading
- The stitching is better than ±100nm
- The alignment errors are around ±500nm
- Can be used for flat alignment for other tools e.g. E-beam

Tips and Tricks

- Bias
  - Correct for size errors in lithography and/or pattern transfer
  - No need to redraw design; possible during conversion
- Mix-and-match
  - Expose same resist in mask aligner and maskless
  - Correct for scaling and shearing (4 mark alignment)
- Optical Proximity Correction
  - Rule-based OPC is possible using Beamer



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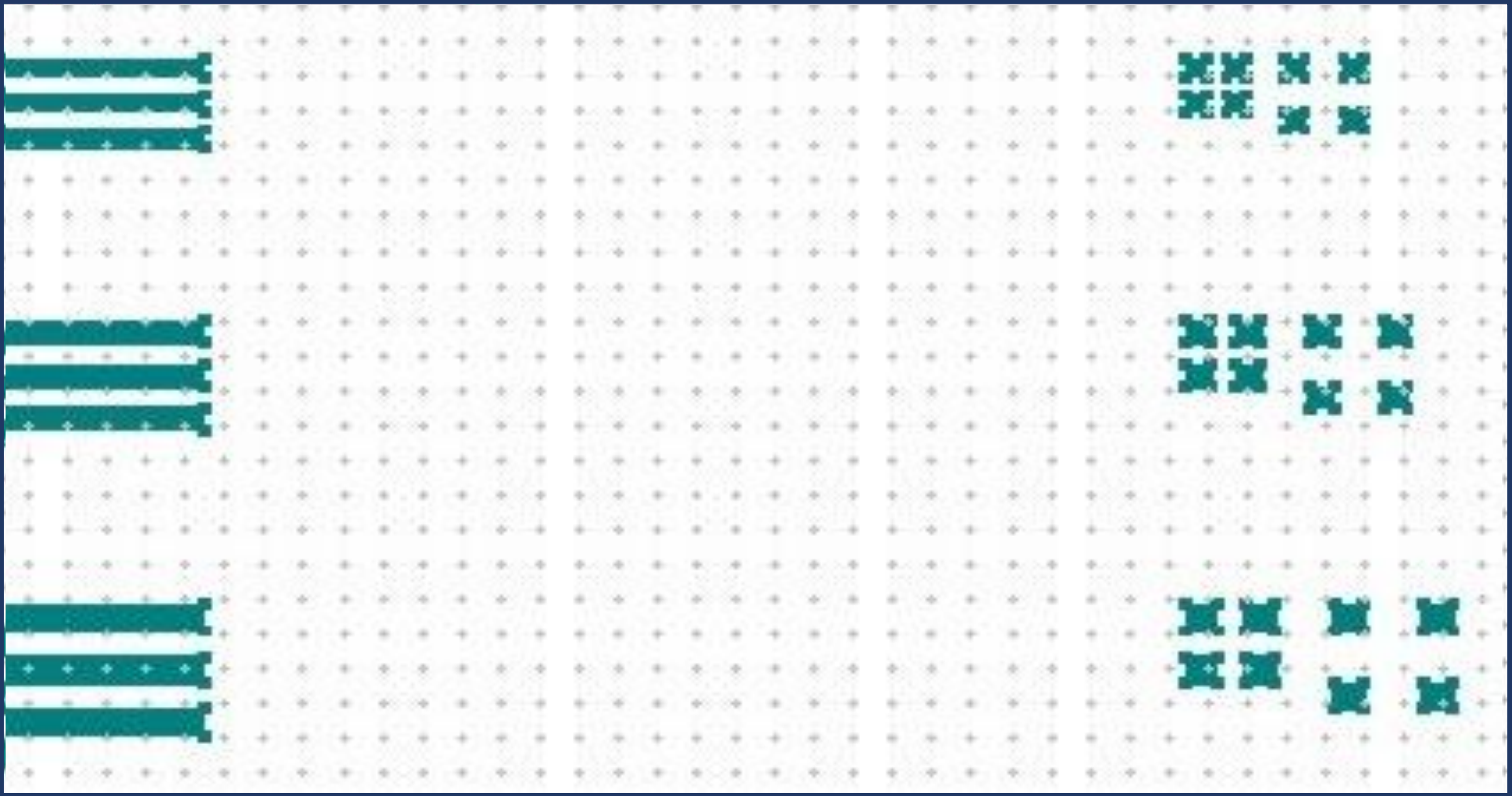
Tricks: Optical Proximity Correction



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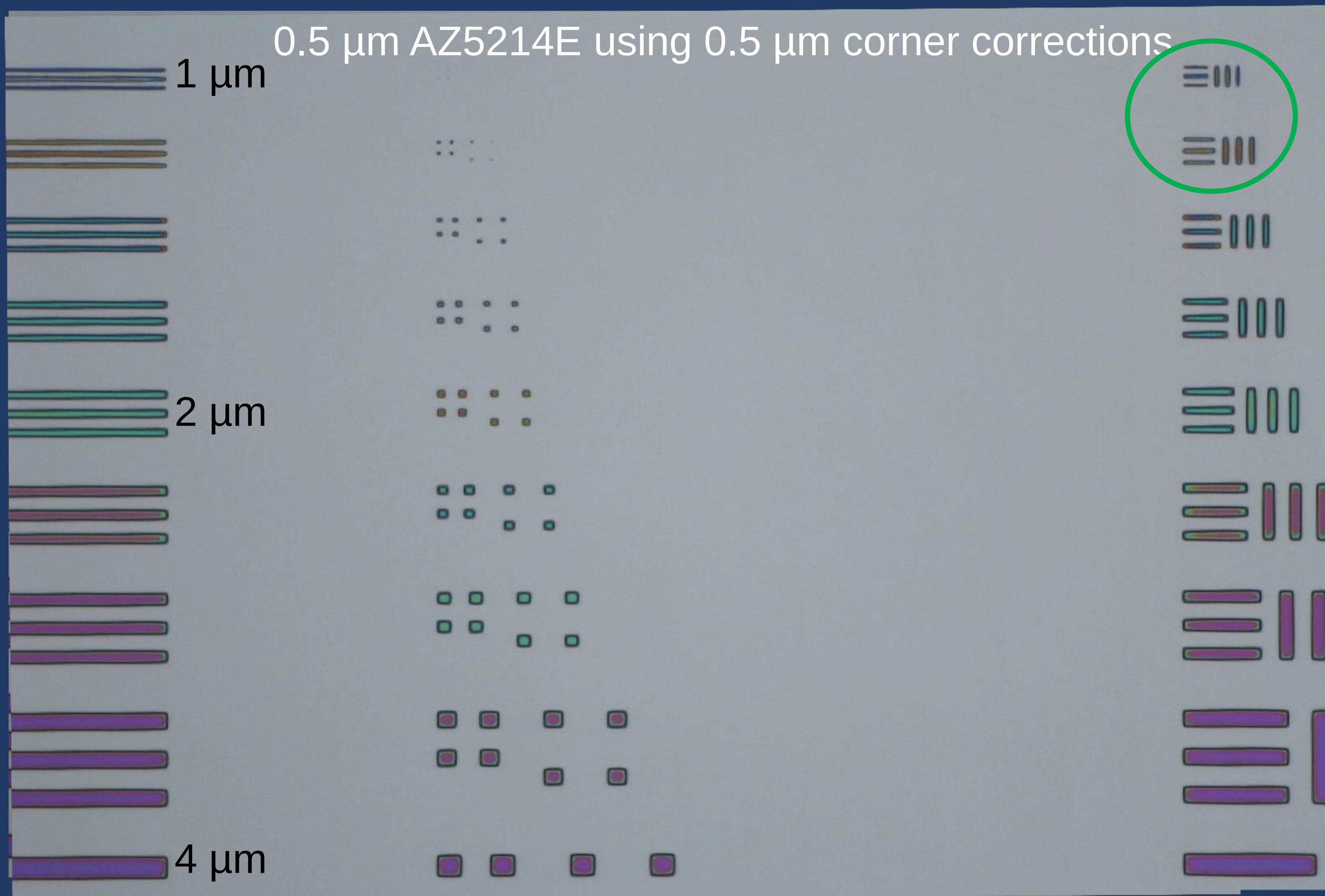
Tricks: Optical Proximity Correction



Nordic nanolab installations

Location	Tool	Contact person
NTNU –Nanolab, *Trondheim (NO)*	MLA 100 MLA 150	Mark Chiappa
UiO – MiNaLab *Oslo (NO)*	µPG 500	Viktor Bobal
USN – *Horten (NO)*	Picomaster 150	Ole Henrik Gusland
NFL – Chalmers, *Göteborg (SE)*	DWL 2000	Johan Andersson
MSL – Ångström, *Uppsala (SE)*	DWL 200	Rimantas Brucas
KTH – Albanova, *Stockholm (SE)*	SmartPrint	Adrian Iovan
UCPH – *Copenhagen (DK)*	µPG 501	Nader Payami
DTU –Nanolab, *Kgs. Lyngby (DK)*	MLA 100 MLA 150 µPG 101	Lean Pedersen

Thank you for your attention

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