Lithography Tool Package

3. Exposure

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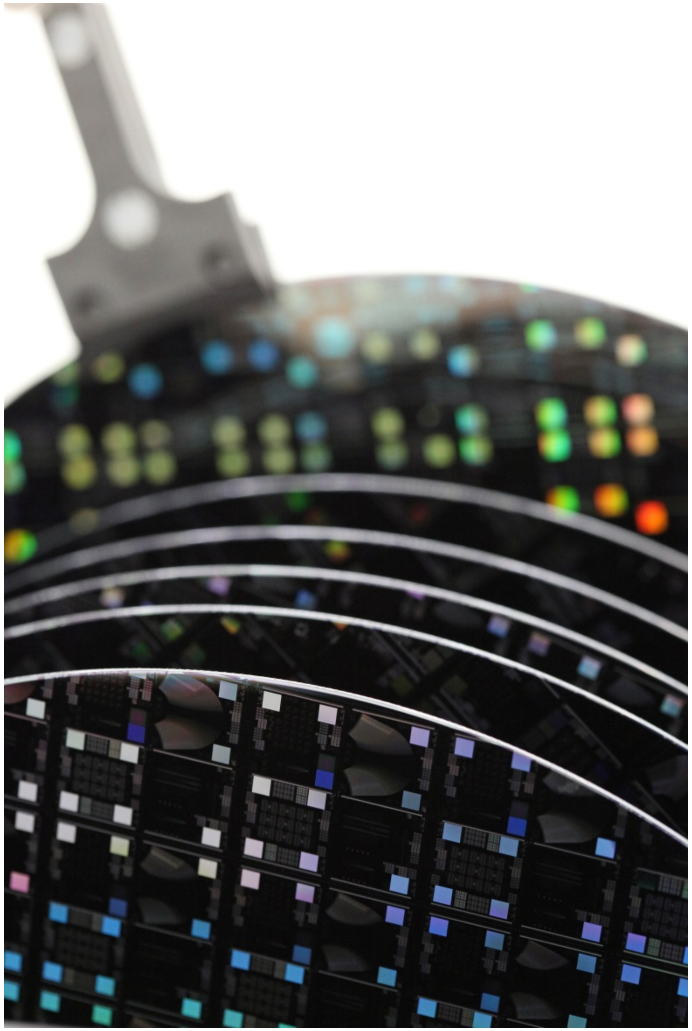

DTU Danchip
National Center for Micro- and Nanofabrication

Outline

1. **Introduction**
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2. **Spin coating**
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   - Pre-treatment
   - Principle
   - Softbake
   - Spin curve
3. **Exposure**
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   - Process parameters
   - Resolution
   - Alignment
4. **Development**
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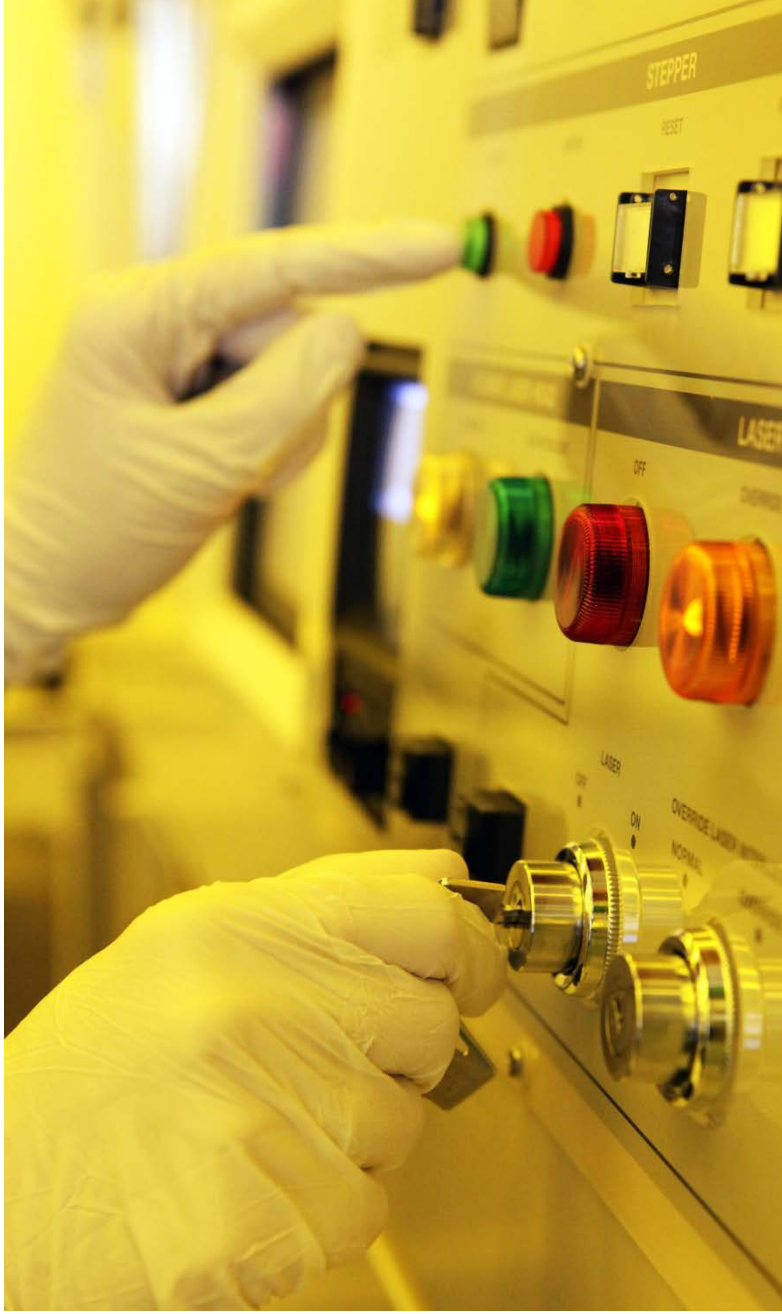
   - Effects
   - Resist tone, photo-chemistry, and contrast
5. **Post-processing and characterization**
   - Post processing
   - Characterization methods
6. **Process effects and examples**
   - Process effects
   - Real life process examples

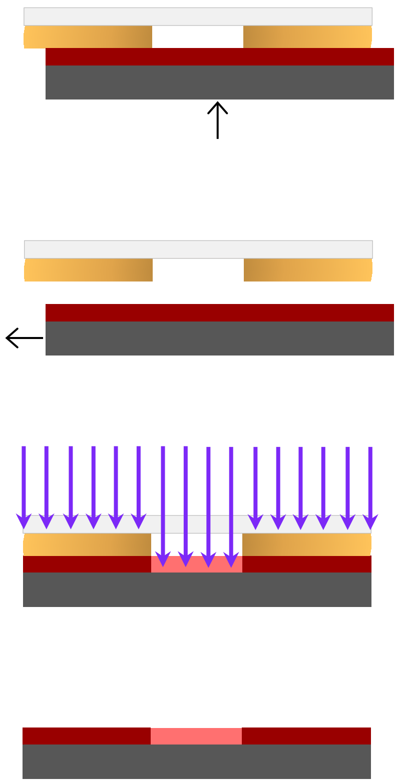


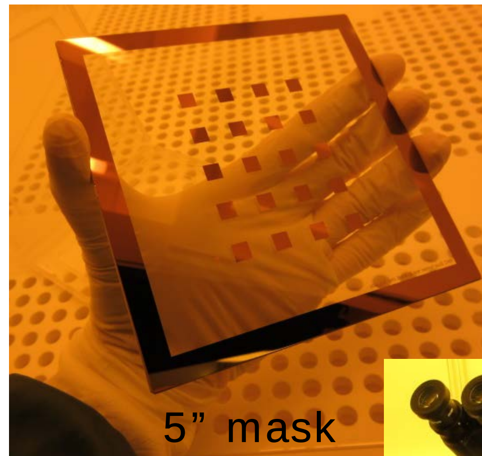
Mask aligning and UV exposure

mask
substrate

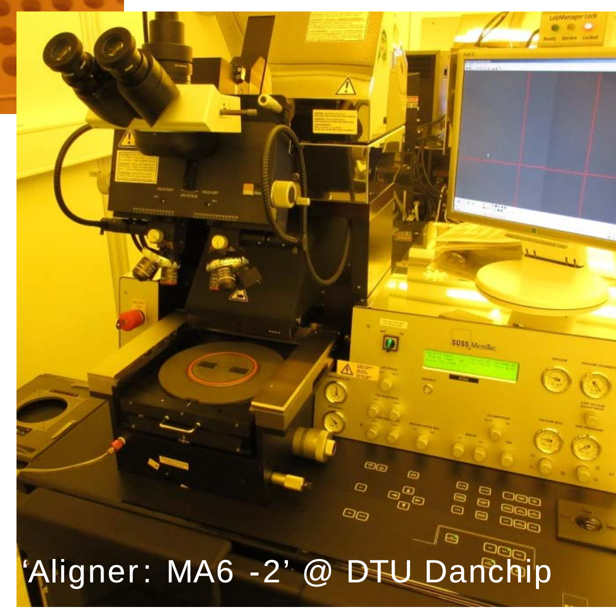
aligning

exposure





5” mask



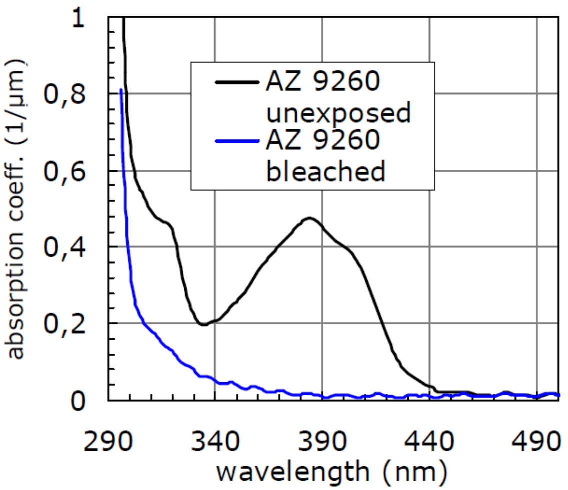
‘Aligner: MA6 -2’ @ DTU Danchip

Photoresist: composition

- **Resin**: Monomers or polymer chains of varying length (solid at RT)
- **Photo-active component** (PAC): Reacts with UV-light during exposure and changes the resin
- **Solvent** (~70%): Dissolves the resin in order to enable coating

- After spin coating and softbake, most of the solvent has evaporated, leaving only resin and PAC in the film on the substrate

- Optical properties
  - Absorbs UV-light (spectral sensitivity)
  - Absorption decreases during exposure = *bleaching*

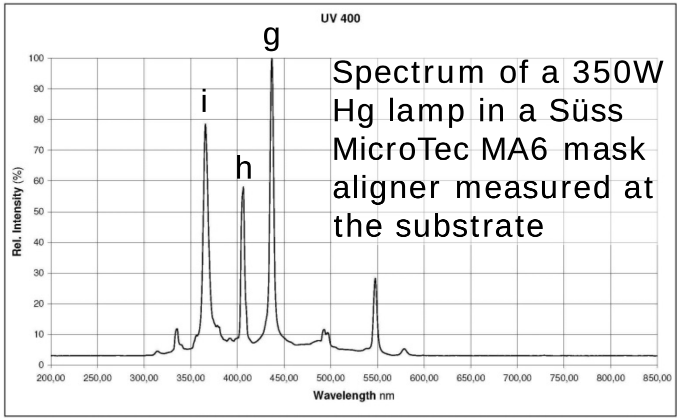


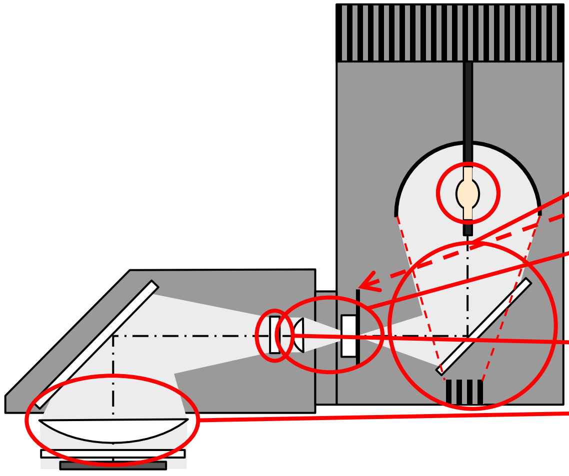
Courtesy of MicroChemicals GmbH

Exposure: procedure and hardware

Exposure source

- Mercury arc lamp: emits spectral lines on top of thermal light
- High power input, most is lost (heat, unwanted wavelengths)
- Most used spectral lines: 365nm (i-line), 405nm (h), 436nm (g)

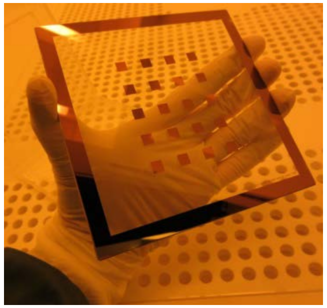


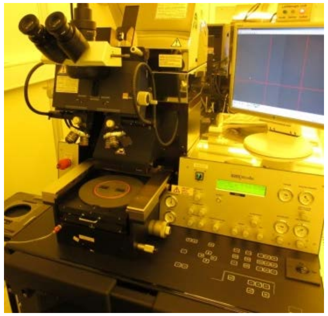


Exposure optics

- Cold mirror: dumps white light
- Shutter: blocks the light
- Fly's eye lens (lens array) and condenser lens: makes the light spatially uniform
- Filter: selects the desired line(s)
- Front lens: collimates the light (parallel beams)

Exposure: procedure and hardware



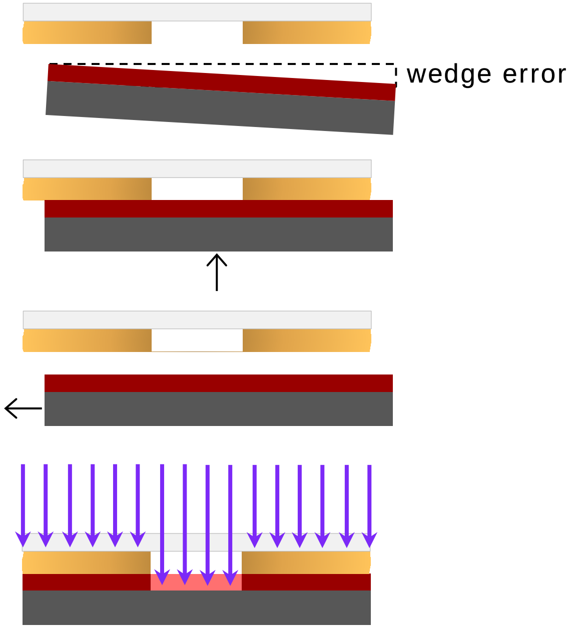


Mask

- A glass plate with chrome pattern
- Commercially produced, usually laser or e-beam lithography
- Anti-reflection coating makes chrome side brown

Exposure procedure

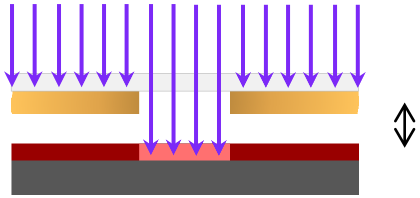
- Load substrate into machine
- Machine performs **W**edge **E**rror **C**ompensation (WEC): substrate surface is made parallel to mask
- Align substrate to mask: the substrate is moved in order to align marks on the substrate to marks on the mask
- Expose substrate: the shutter is opened for a predefined time



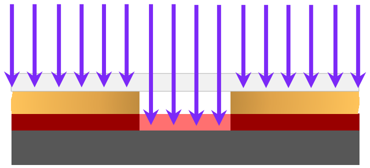
Exposure: process parameters

Exposure mode

- **Proximity:** mask and substrate are separated by a gap of e.g. 10µm during exposure
  - Pros: the mask does not get dirty → hundreds of prints
  - Cons: reduced resolution (line broadening, corner effects)

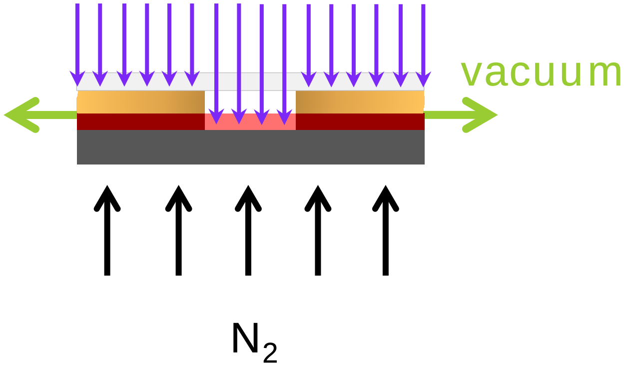


- **Contact:** mask and substrate are in close contact during exposure
  - Pros: highest resolution
  - Cons: the mask gets dirty → a few prints
  - Subtypes: soft, hard, vacuum



Exposure: contact printing subtypes

- ***Soft contact***: many decent prints
  - Same force as WEC
- ***Hard contact***: ~10 good, uniform prints
  - The vacuum holding the substrate on the chuck is replaced by a N_2 pressure, forcing substrate and mask in closer contact
  - 'Hard Contact (HC) wait time' is typically set to 10 sec (time between contact and exposure)
- ***Vacuum contact***: 1 very good print, thereafter only perfect in areas
  - A chamber is created between chuck and mask (by inflating a rubber ring around the substrate), and the space between substrate and mask is evacuated



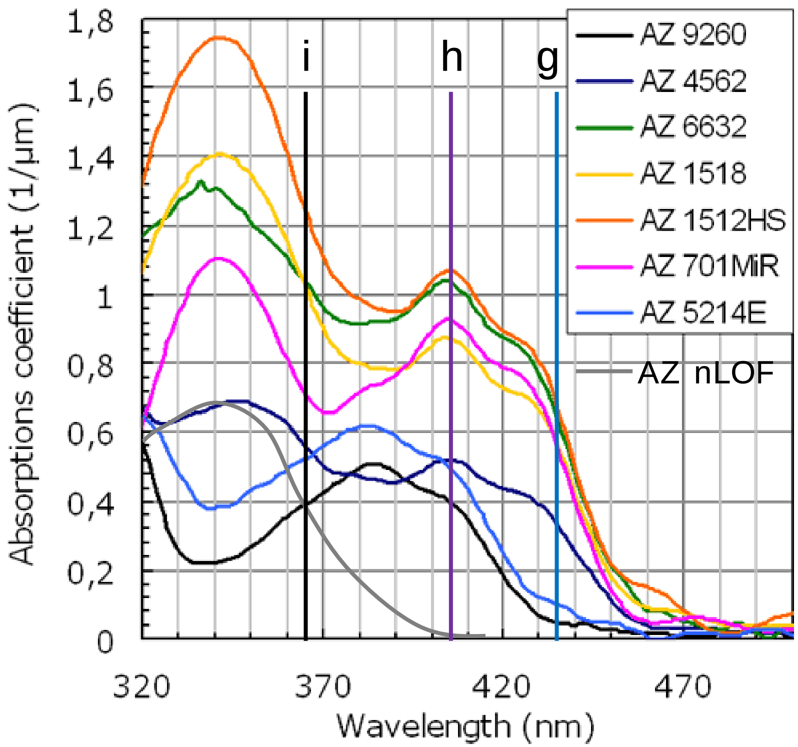
Exposure: process parameters

Exposure dose

- Dose = intensity · time
- Unit is mW/cm^2 · s = mJ/cm^2

- Optimal dose is a function of:
  - Resist; sensitivity, thickness, softbake parameters
  - Exposure light; wavelength, intensity
  - Developer; chemistry, temperature, time
  - Mask material (absorption)

Spectral sensitivity



Courtesy of MicroChemicals GmbH

UV Resist	MiR 701	nLOF 2020	5214E	4562	SU-8
Thickness	1.5–4 µm	1.5–4 µm	1.5–4 µm	5–10 µm	4–200 µm

Exposure: resolution

Theoretical resolution limit

$$R = k\sqrt{\lambda\left(s + \frac{z}{2}\right)}$$

s: gap between mask and resist

z: resist thickness

λ: wavelength of exposure light

k: a constant, theoretically 1.5

Adapted from Marc J. Madou "*Manufacturing Techniques for Microfabrication and Nanotechnology*" 2011. Valid for a (one dimensional) grating with period 2R.

- Contact (s=0): R = 0.8µm. Mask upside down (s=2.3mm): R = 43µm!

Practical resolution

- In practice, resolution is decreased by resist contrast, stability (aspect ratio), and adhesion to substrate, as well as the contact during printing (both across the substrate and from print to print)
- k > 1.5 → k ≈ 2.5
- Critical dimension (smallest structure/gap) should always be CD > R
- 3µm is possible everyday; 1.25µm only when you are lucky

Exposure: resolution exercise

- What is the effect of a 2µm edge bead on the resolution limit of i-line exposure (365nm) of a 2µm resist film in the case of contact printing, and proximity printing (proximity gap = 10µm), respectively?

- Contact printing:
- R = 0.91µm without edge bead (s=0µm)
- R = 1.57µm with 2µm edge bead (s=2µm); almost 75% increase

- Proximity printing:
- R = 3.01µm without edge bead (s=10µm)
- R = 3.27µm with 2µm edge bead (s=12µm); less than 10% increase
- Why does the gap still increase in proximity mode?

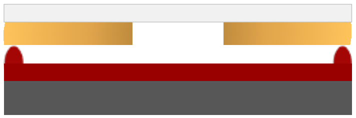
$$R = k\sqrt{\lambda\left(s+\frac{z}{2}\right)}$$

s: gap between mask and resist

z: resist thickness

λ: wavelength of exposure light

k: a constant, theoretically 1.5

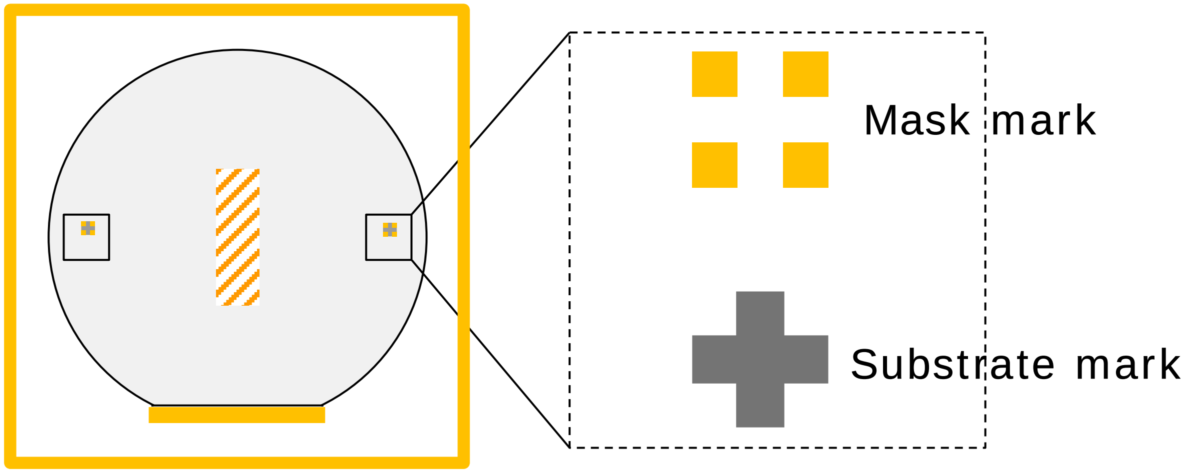


WEC defines “0”

Exposure: first print versus alignment

- First print: Exposure on a blank substrate. In a first print, the mask is often aligned to the flat of the substrate or chip

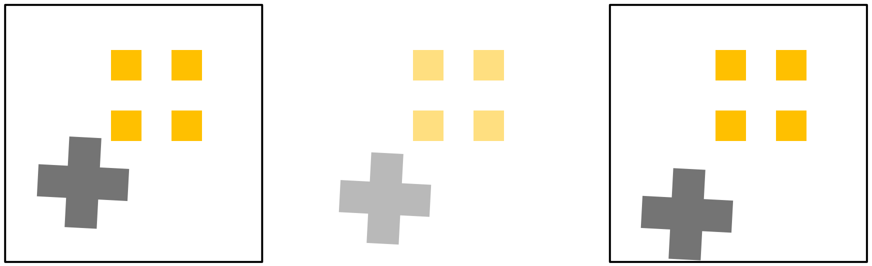
- Alignment: Using stage translation and rotation, the substrate is aligned to the mask



http://labadviser.danchip.dtu.dk/index.php/Specific_Process_Knowledge/Pattern_Design

Exposure: alignment

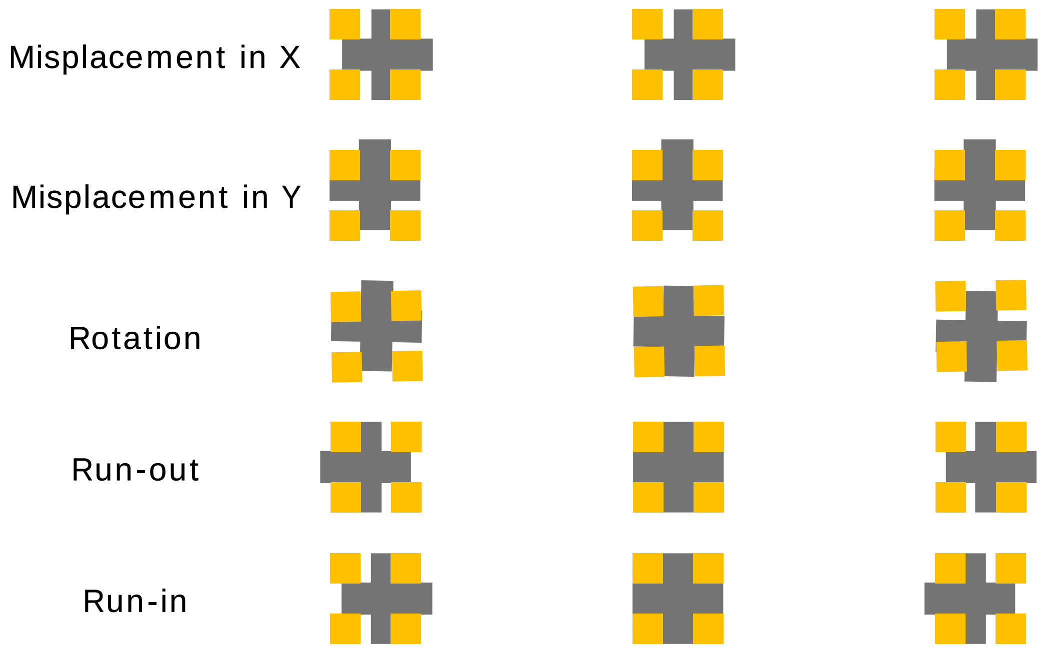
- Using stage translation and rotation, the substrate is aligned to the mask



Alignment accuracy

- Manual alignment to ±1µm is possible, but expect up to ±3µm
- Remember to include tolerance in your design!

Misalignment



Accuracy depends on:

- Alignment mark design
- Operator experience
- Previous processing of substrate
- Equipment condition