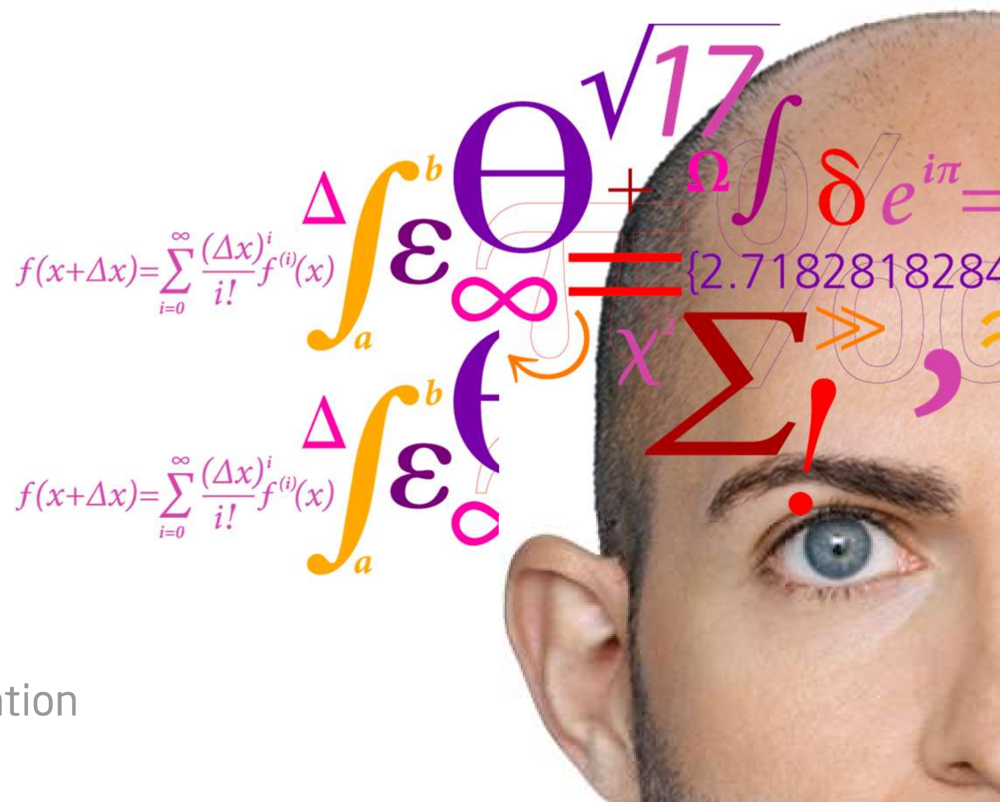
Lithography Tool Package

Exposure



DTU Danchip

National Center for Micro- and Nanofabrication

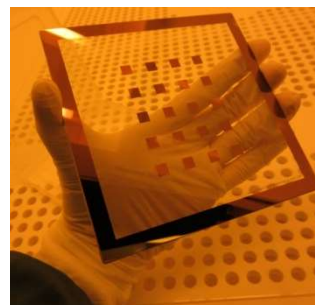
Exposure: outline

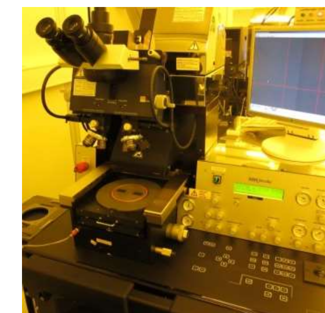
- Principle
  - Load, WEC, align, expose
- Light source and optics + mask
- Exposure modes
  - Proximity
  - Contact (soft, hard, vacuum)
- Exposure dose + influences
- Theoretical resolution limit + practical limit, CD
- Alignment + tolerance
- Exercise: The effect of edge bead on resolution

Exposure: procedure and hardware

Mask

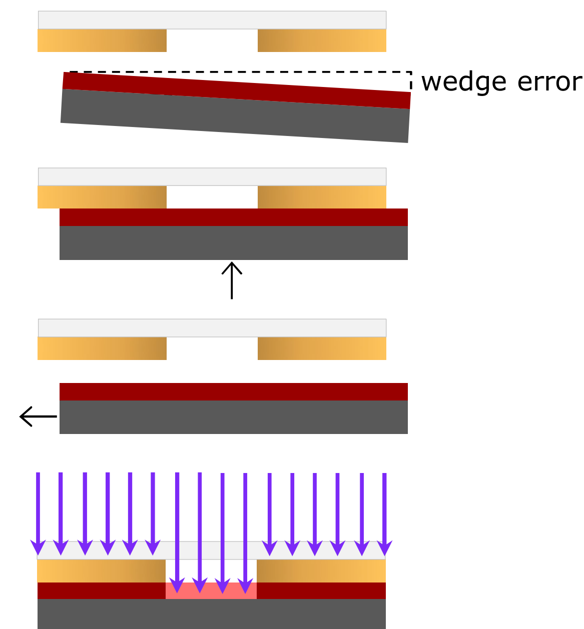
- A glass plate with chrome pattern
- Commercially produced, usually laser or e-beam lithography
- Anti-reflection coating makes chrome side brown





Exposure procedure

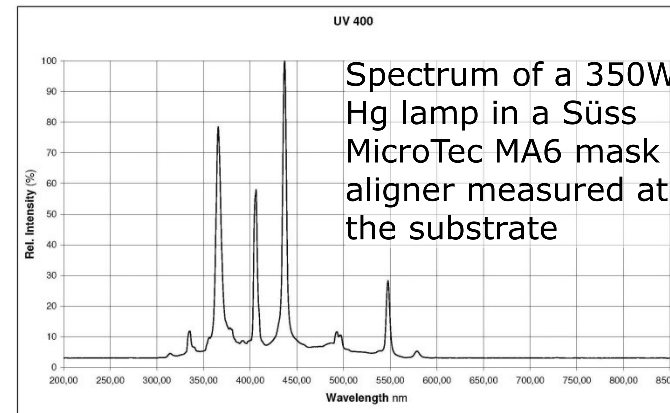
- Load substrate into machine
- Machine performs **W**edge **E**rror **C**ompensation: substrate surface is made parallel to mask
- Align substrate to mask: the substrate is moved in order to align marks on the substrate to marks on the mask
- Expose substrate: the shutter is opened for a predefined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



Exposure: procedure and hardware, cont.

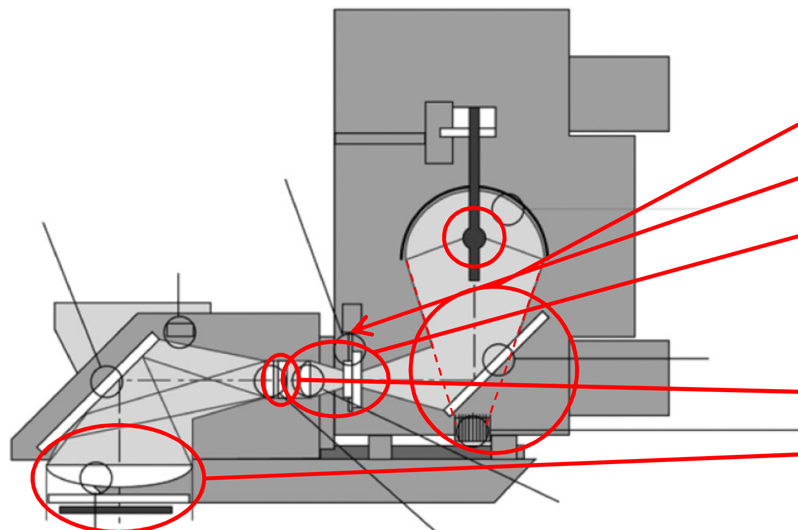
Exposure source

- 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, 405nm, 435nm



Exposure optics

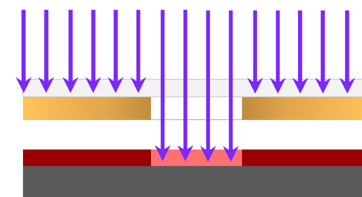
- Cold mirror: dumps white light
- Shutter: blocks the light
- Fly's eye lens (lens array) and condenser lens: makes the light spatially uniform
- Filter: selects the desired line(s)
- Front lens: collimates the light (parallel beams)

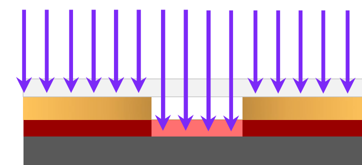


From Sami Franssila, "*Introduction to Microfabrication*" 2010

Exposure: 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

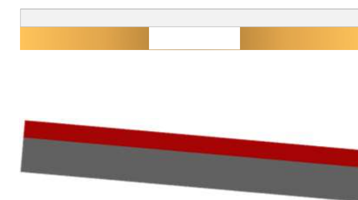
Exposure dose

- Dose = intensity * time [$mW/cm^2 * s = mJ/cm^2$]
- Optimal dose is a function of many variables
  - Resist; sensitivity, thickness, softbake parameters
  - Exposure light; wavelength, intensity
  - Developer; chemistry, temperature, time
  - Mask material: absorption (quartz or other glass)

Exposure: details

Wedge Error Compensation

- The stage pushes the substrate on the chuck against the mask while being able to tilt (roll and pitch)
- Once contact has been established, the tilt is locked, enabling the stage to move down while maintaining parallelism



Contact printing

- *Soft contact*: many good prints
  - Same force as WEC
- *Hard contact*: ~10 very good, uniform prints
  - The vacuum between substrate and chuck is replaced by a N_2 pressure, forcing substrate and mask in closer contact
- *Vacuum contact*: 1 perfect 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

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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 (two dimensional) grating with period 2R.

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 ≈ 2.5
- Critical dimension (minimum feature size) should always be CD > R
- 3μm is possible everyday; 1.25μm only when you are lucky

Alignment accuracy

- Manual alignment to ±1μm is possible
- Remember to include tolerance in your design!

Exposure: 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
- R = 1.57µm with 2µm edge bead; almost 75% increase

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

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