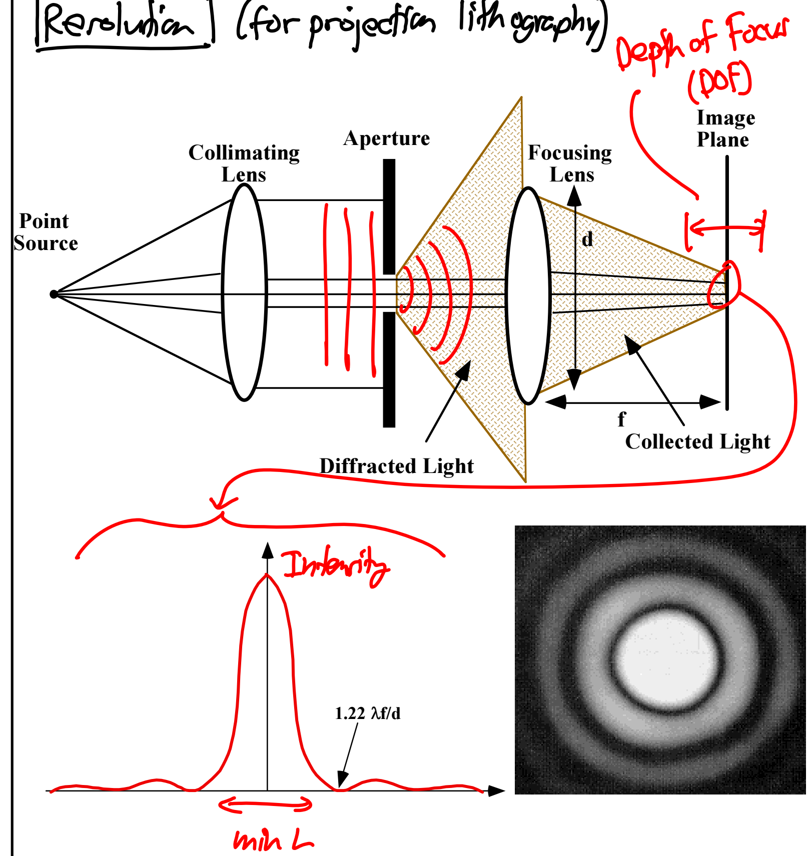
Lecture 9: Lithography III / Oxidation I

- Announcements:
  - HW#4 online
  - Module 2 on Oxidation online
- ---------------------------------------
- Lecture Topics:
  - Masks & alignment
  - Lambda design rules
  - Four main components of lithography
    - Radiation source
    - Mask
    - Photoresist
    - Exposure system
  - Resolution
  - Linewidth control
  - Alignment accuracy
  - Oxidation
  - Oxidation Theory
  - Oxidation Graphs
  - Dopant Redistribution During Oxidation
- ---------------------------------------
- Last Time:

over

Resolution (for projection lithography)



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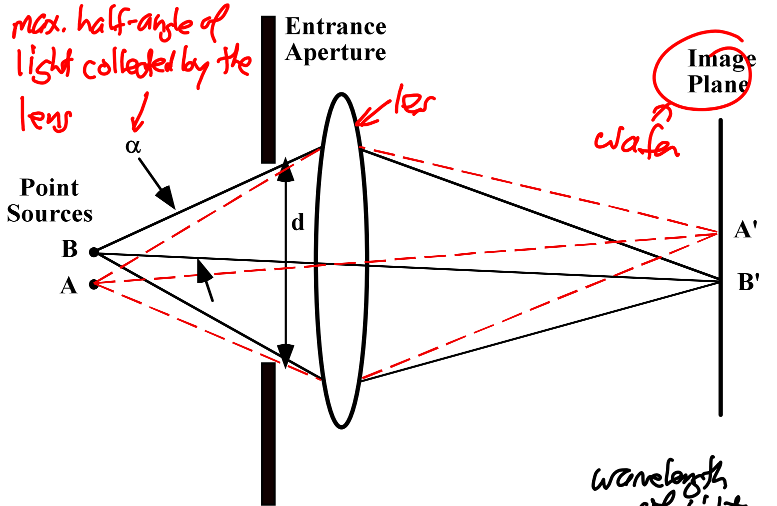


Assume diffraction-limited system:

$$\text{minimum } L \triangleq \text{min. feature size} = \frac{0.6\lambda}{NA}$$

- λ: wavelength of light
- minimum L: 2λ (from before)
- min. feature size: want small
- NA: Numerical Aperture
- Design Rules — different

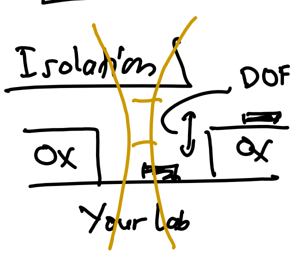
$$NA = n \sin\alpha$$

- n: refractive index

$$\text{Depth of Focus} \triangleq DOF = \pm \frac{\lambda}{2(NA)^2}$$

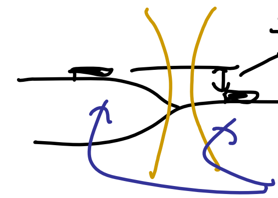
- λ: wavelength of light
- DOF: want BIG
- X conflict (between want small min. feature size and want big DOF)

Isolation



DOF must be large enough to stay in focus over this range

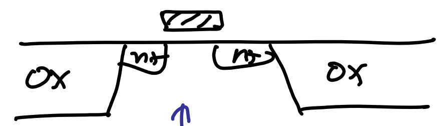
More advanced than your lab → LOCOS



LOCOS → good for ~0.25 μm

Both top & bottom features in focus & well resolved

Latest CMOS: (at least more modern)

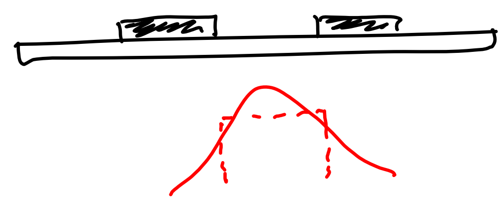


flat → allows for much smaller DOF → then allows better min. L

Ex. λ: 436 nm (g-line), NA: 0.3 → min L: 0.9 μm, DOF: 2.7 μm

Ex. λ: 200 nm, NA: 0.5 ⇒ min L: 0.27 μm = 270 nm, DOF: 0.4 μm = 400 nm

Aside: Phase-Shifting mask



→ *

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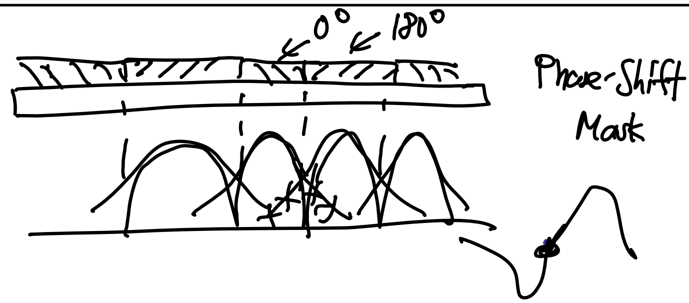
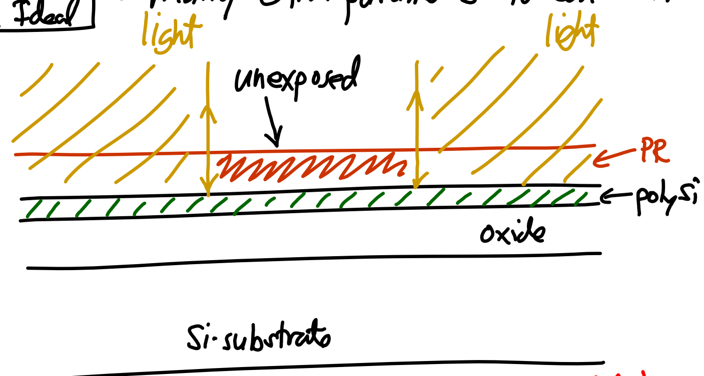
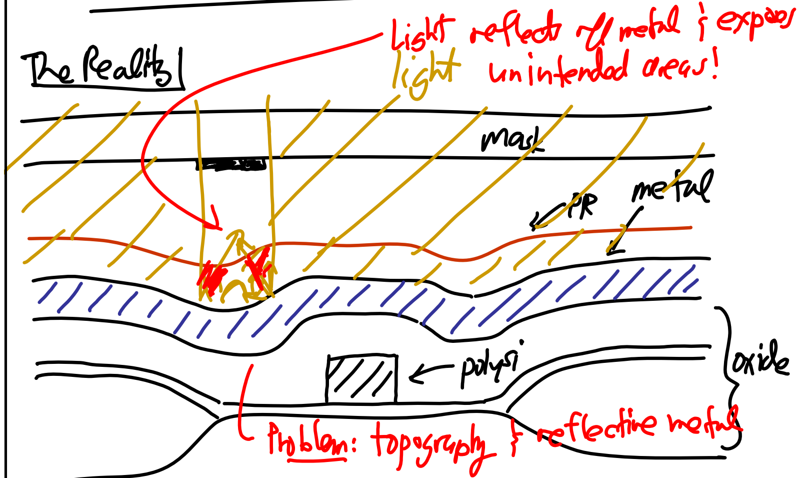


* → But... this is all theoretical!
↳ many other parameters to consider!

The Ideal!



The Reality!

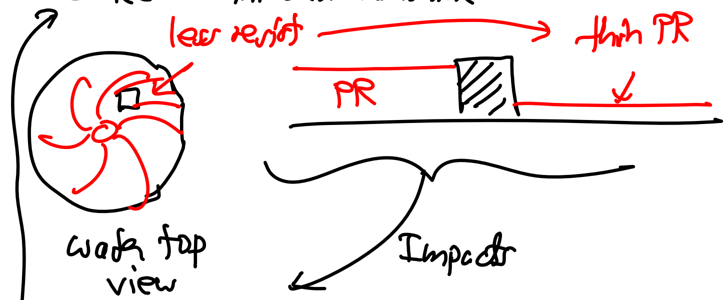


Linewidth Control

→ depends on:

① Optical System

② Resist Thickness Variation



③ Exposure & Development Time

④ Reflectivity of the Substrate — also influences

⑤ Topography!

Active Area Mask

Ex. Say the theoretical min. $L \approx 0.9\,\mu m$

What is the practical min. L?

↳ depends the mask level:

↳ the later the mask, the more the topography! → worse min. L

e.g., gate mask → min. $L \sim 1\,\mu m$

metal mask → min. $L \sim 1.5\,\mu m$

↳ What can we do about this?

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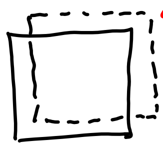
Some tricks:

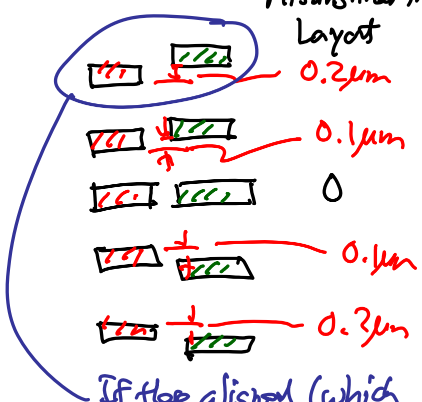
1. Anti-reflection coating
2. Multi-level PR (for small topography)

3. Dye PR → add a dye to the PR that absorbs reflected light (@ the needed λ).

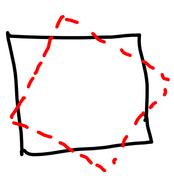
Alignment Accuracy

1. Translational Error:

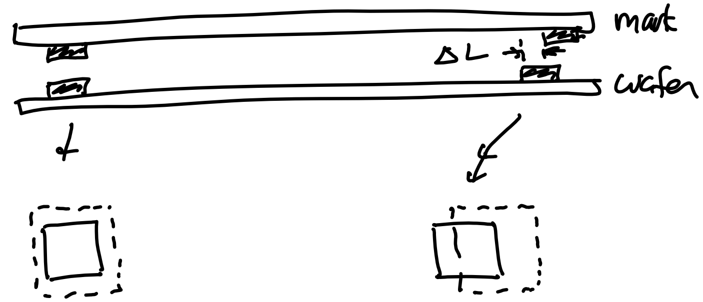




2. Rotational Error:



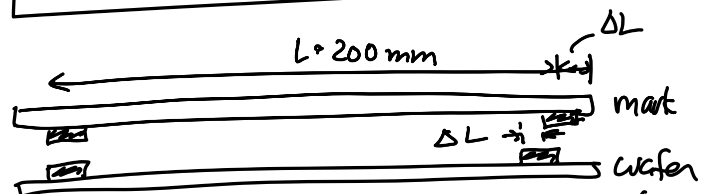
3. Run-in/Run-out: when one part of the wafer is aligned, but another part is not.



Ex. Case: Contact Lithography

Define Thermal Expansion Coefficient

$$\alpha = \text{thermal expansion coefficient} = \frac{\Delta L / L}{\Delta T} = \frac{1}{L}\frac{\Delta L}{\Delta T} \approx \frac{1}{L}\frac{\partial L}{\partial T}$$



$(\alpha_{mask} - \alpha_{Si}) = \alpha = 10\times10^{-6}/°C$ $\mu = 10^{-6}$

ppm → "parts per million"

$\Delta T = 1°C$

$\alpha = \frac{1}{L}\frac{\Delta L}{\Delta T} \rightarrow \Delta L = \alpha L \Delta T = (10\mu)(200m)(1)$ (m = 10^{-3})

$\therefore \Delta L = 2\mu m$

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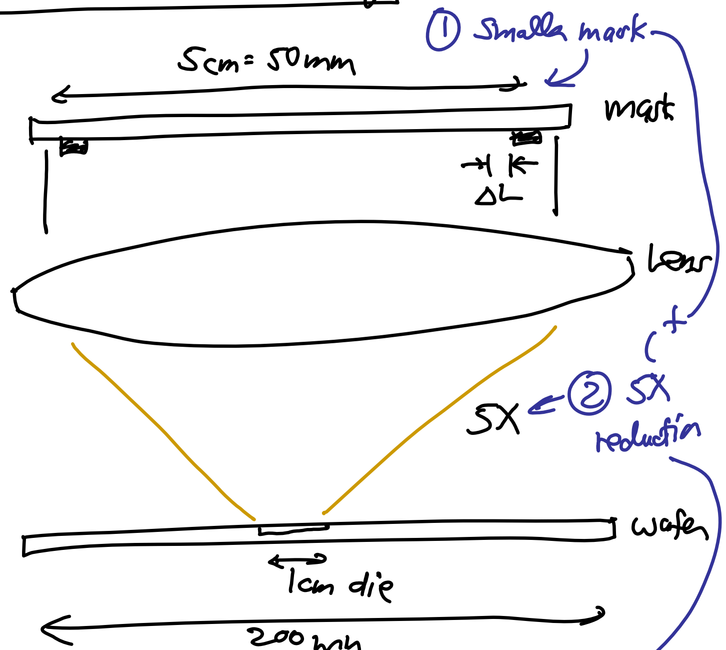
⇒ this is why projection stepper lithography really shines!

Projection Stepper Lithography



$$\Delta L = \frac{\alpha L \Delta T}{5} = \frac{(10\mu)(50m)(1)}{5} = 0.1\mu m$$

better alignment resistance against run-in/run-out errors!

Thermal Oxidation of Silicon

⇒ achieved by heating the Si wafer to a high temperature (~900°C – 1200°C) in an atmosphere containing pure O_2 or water vapor

⇒ enabling reactions:

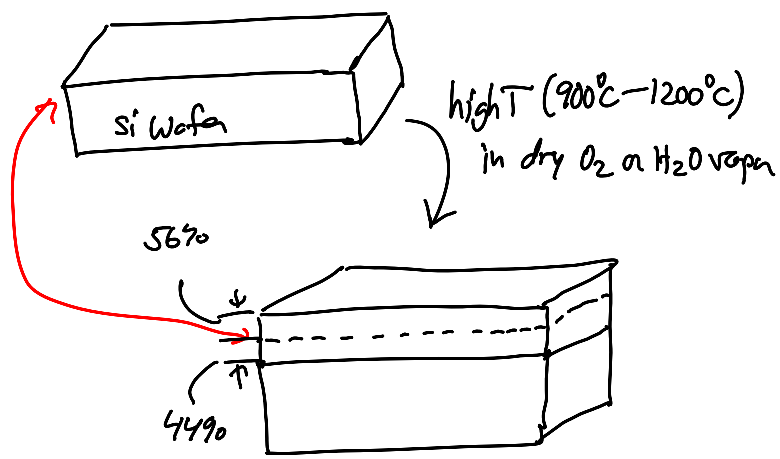
For dry O_2:

$$Si + O_2 \rightarrow SiO_2$$

For Water Vapor:

$$Si + 2H_2O \rightarrow SiO_2 + 2H_2$$

Schematically:



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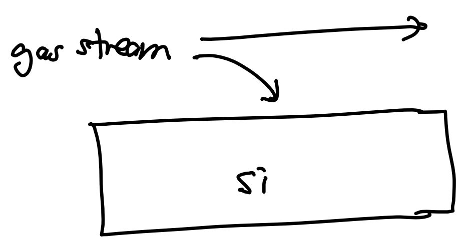
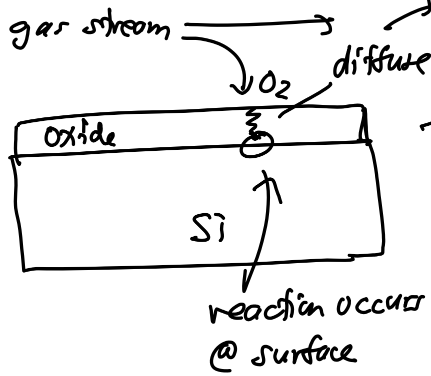
Modeling: Deal-Grove or "Linear-Parabolic" Model

① Initially: (no oxide on the surface)



growth rate determined by the reaction rate
↓
largely linear

② As oxide builds up:



Reactant must diffuse to Si surface where the oxidation reaction occurs
↓
slows down growth rate
↓
less than linear
↓
parabolic

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