CHE323/CHE384
Chemical Processes for Micro- and Nanofabrication
www.lithoguru.com/scientist/CHE323

Lecture 57
Lithography:
Resolution Enhancement
Technologies, part 1

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What Is Resolution?

- As a proxy for lithographic quality, use depth of focus (DOF):

DOF: The range of focus that keeps a given feature in spec (CD, sidewall angle, resist loss) over a given range of exposure.

Resolution: The smallest feature of a given type that can be printed with at least a given minimum depth of focus.

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The Two Resolutions

- There are two distinct resolutions in optical lithography
  - The smallest pitch (and half-pitch)
  - The smallest feature (critical dimension, CD)

Feature Size (CD)

Pitch

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Pitch Resolution

$$pitch\ resolution = k_{pitch}\ \frac{\lambda}{NA}$$

- k_{pitch} has a hard cut-off at 0.5
- To go below $k_{pitch} = 0.7$ requires tremendous effort
- You can't go lower than 0.5, unless you use double patterning

Illumination Wavelength (λ)

Mask

Objective Lens Numerical Aperture (NA)

Wafer

4

Feature Resolution
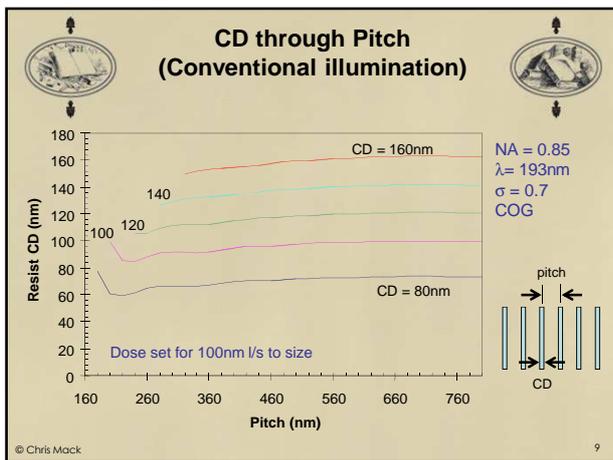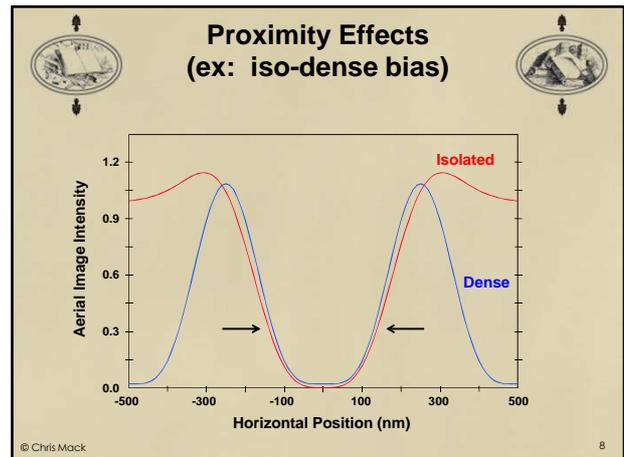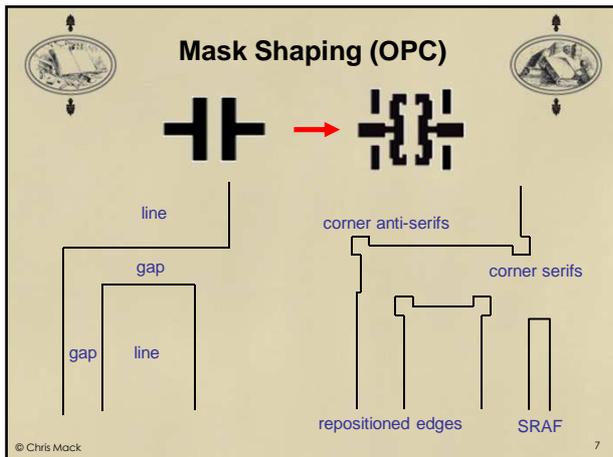
$$resolution = k_1\ \frac{\lambda}{NA}$$

- k_1 has no hard cut-off for an individual feature
- Feature resolution is limited only by CD control
  - The magnitude of the process errors
  - The process latitude
- Feature resolution is always equal to or better than half-pitch resolution

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Resolution Enhancement Technologies (RET)

- Optical Proximity Correction (OPC)
- Off-Axis Illumination (OAI)
- Phase-Shifting Masks (PSM)

Optical Proximity Correction (OPC)

Off-Axis Illumination (OAI)

Lens

Mask

Wafer

Conventional   Annular   Quadrupole

Phase Shifting Mask (PSM)

Quartz

Phase Shifted Space

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Mask Shaping (OPC)

line

corner anti-serifs

gap

corner serifs

gap   line

repositioned edges   SRAF

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Proximity Effects
(ex: iso-dense bias)

Isolated

Dense

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CD through Pitch
(Conventional illumination)

CD = 160nm   NA = 0.85
                     λ = 193nm
140   σ = 0.7
120   COG
100

pitch

CD = 80nm

CD

Dose set for 100nm l/s to size

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OPC Basics

- Rule-based OPC
  - a table lookup for needed corrections as a function of CD and pitch
  - simple and fast, but accuracy is not adequate below about 180 nm
- Model-based OPC
  - use calibrated model to predict the correction needed for any CD and pitch, or 2D pattern
  - Every generation requires greater accuracy, making models more complex and slower
  - Empirical resist models require recalibration with every process change

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OPC Review

- Proximity effects vary greatly depending on NA and illuminator, but also on resist and mask making processes
- *Rule-based OPC* is simple and fast, but accuracy is not adequate below about 180-nm design rules
- *Model-based OPC* works very well, but is slow and requires complex model calibration
- Chip technologies at and below the 250-nm node *require* OPC

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Lecture 57:
What have we Learned?

- What are the two types of resolution?
- What are the three main RET approaches?
- Why is OPC needed in optical lithography?
- What are the two main types of OPC, and what are their advantages and disadvantages?

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