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Lecture 45
Lithography:
Illuminating the Mask

Chris A. Mack
Adjunct Associate Professor

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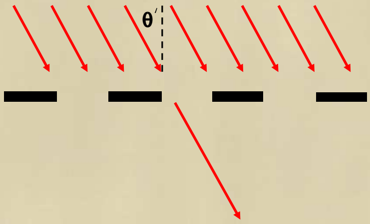
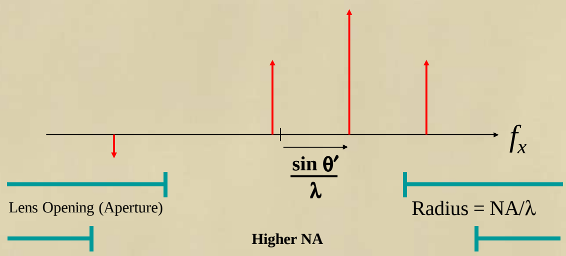
Oblique Illumination



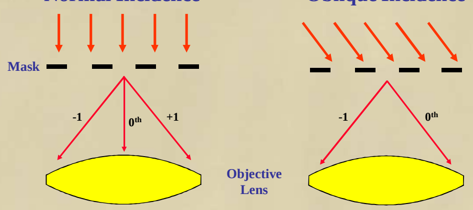
Zero order: The diffraction order that passes through the mask without changing direction

Shifted Spatial Frequency Diagram

- For plane waves incident on the mask with angle θ′, the result is a shift in the spatial frequency diagram of sinθ′/λ.



Theoretical Resolution



Normal incidence: $\frac{1}{p_{min}} = \frac{NA}{\lambda}$

Oblique incidence: $\sin\theta_{max} = 2NA = \lambda/p_{min}$

Minimum half-pitch: $R = \frac{p_{min}}{2} = 0.5\frac{\lambda}{NA}$ $R = \frac{p_{min}}{2} = 0.25\frac{\lambda}{NA}$

Traditional Limits of Lithography Resolution

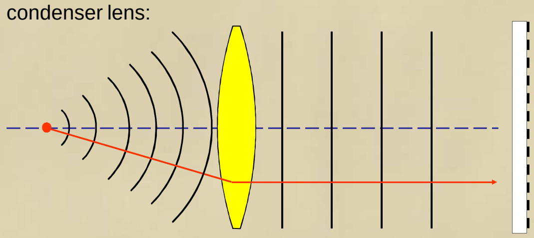
- Generalized Rayleigh Resolution:

$$R = k_1\frac{\lambda}{NA}$$

- For 3-beam imaging, $k_1 \geq 0.5$
- For 2-beam imaging, $k_1 \geq 0.25$

Mask Illumination

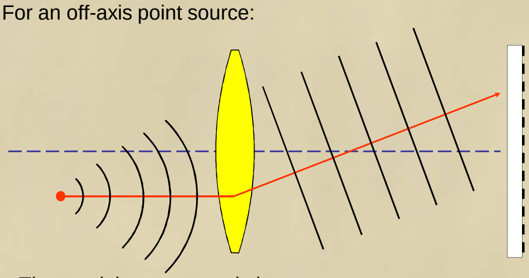
- Consider a point source at the focal point of the condenser lens:



- The result will be normal plane waves

Mask Illumination

- For an off-axis point source:



- The result is non-normal plane waves

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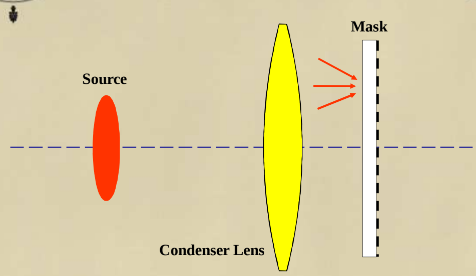
Mask Illumination



An *extended source* results in a range of angles striking the mask

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Spatial Coherence of Illumination

- Coherent
  - Plane wave illumination (one direction)
  - Point source illumination
- Incoherent
  - A continuous spectrum of plane waves with incident angles ranging ±90 °
  - Infinitely big light source
- Partially Coherent
  - A finite, non-zero range of incident angles of plane waves
  - Finite, non-zero size source

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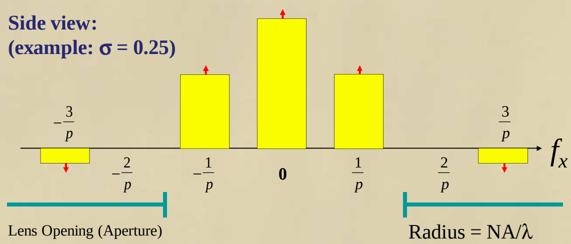
Partial Coherence

- The angular range of the source spreads the diffraction points into broad spots.

Side view:
(example: $\sigma = 0.25$)



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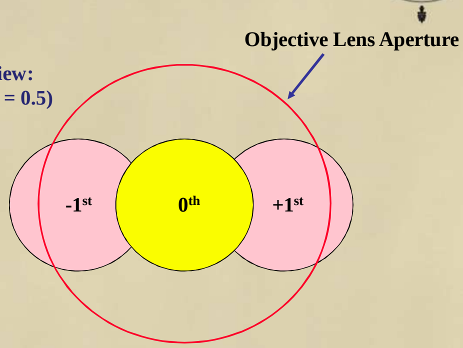
Partial Coherence

Top down view:
(example: $\sigma = 0.5$)



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Partial Coherence Factor

- For a circular source, we can describe the illumination in two equivalent ways:
  - the size of the spot at the objective lens entrance pupil
  - the range of angles of the light striking the mask
- We define the the partial coherence factor as

$$\sigma = \frac{\textit{diameter of illumination spot}}{\textit{diameter of objective lens entrance pupil}}$$

or, $$\sigma = \frac{\sin(\theta'_{max})}{NA_o}$$

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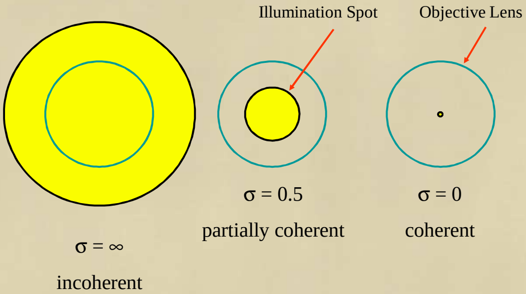
Partial Coherence



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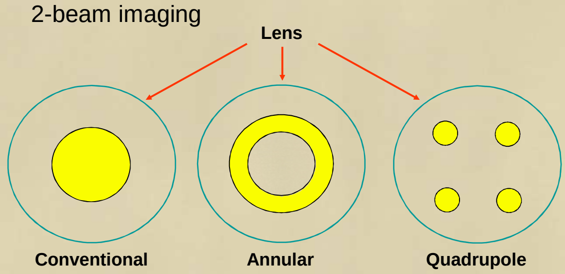
Off-Axis Illumination (OAI)

- OAI - Eliminate the on-axis component, achieve 2-beam imaging



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Partially Coherent Images

- Each point in the source will produce an image at the wafer
- Every point in the source has a randomly changing phase with respect to other points in the source (we say the points are incoherently related to each other)
- The final image is the superposition of the image intensities that come from each source point
- The easiest way to calculate these images is with a lithography simulator

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Illumination Review

- *Oblique* mask illumination results in a *shift* in the position of the diffraction pattern
- *Partial Coherence* defines the range of angles illuminating the mask relative to the objective lens NA (coherent = one angle, incoherent = all angles)
- *Resolution* for lines and spaces can be (simply) defined as the smallest feature that allows two diffracted orders to pass through the lens. Proper (tilted) illumination (2-beam imaging) can double resolution compared to coherent illumination (3-beam imaging)

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Lecture 45: What have we Learned?

- How does oblique illumination affect the diffraction pattern?
- What is the Rayleigh resolution criterion?
- What are the minimum values of k_1 for 2-beam and 3-beam imaging?
- Define coherent, incoherent, and partially coherent illumination
- What is off-axis illumination?

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