CHE323/CHE384
Chemical Processes for Micro- and Nanofabrication
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Lecture 41
Lithography: Diffraction, part 1

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Reading: Chapter 7, *Fabrication Engineering at the Micro- and Nanoscale*, 4th edition, Campbell

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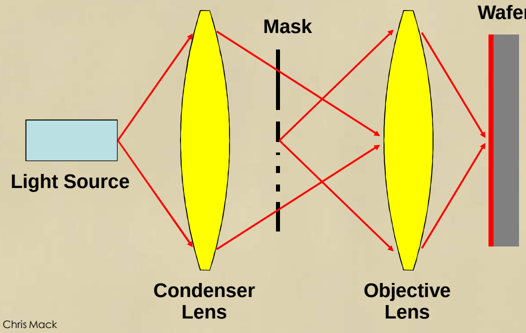
Generic Projection System



Diffraction Limited Imaging

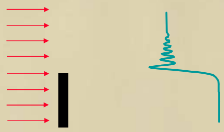
- If an imaging lens is perfect (i.e., it has no aberrations), then the optical system is said to be "Diffraction Limited"
  - Only diffraction effects reduce the quality of the final image
  - Diffraction limited performance is an ideal that can never be completely achieved
- In a perfect world, we are still limited by diffraction!

Basic Imaging System

- Light passing through the mask is diffracted
- The diffraction pattern spreads as it travels away from the mask
- The *objective lens* collects a portion of the diffraction pattern and forms an image of the mask at the focal plane
- The finite size of the objective lens means that some of the diffracted light is lost

Diffraction

- Common Definition:
  - The bending of light as it passes through a slit or past an edge.
- More Correct Definition:
  - A description of the propagation of light, including the effects of boundary conditions.



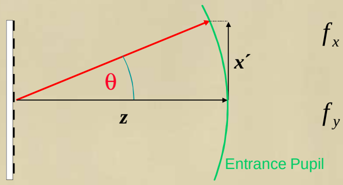
Why Does Light Diffract?

Huygens' Principle: Every point on the wavefront radiates as a spherical wave. The new wavefront is the sum (interference) of these individual spherical wavefronts.

Wavefront: a surface of constant phase of the light.

Spatial Frequency

- Spatial frequencies are scaled coordinates in the diffraction plane



$$f_x = \frac{x'}{\lambda z} = \frac{\sin\theta_x}{\lambda}$$

$$f_y = \frac{y'}{\lambda z} = \frac{\sin\theta_y}{\lambda}$$

x', y' = coordinates in the diffraction plane
z = distance from mask to diffraction plane

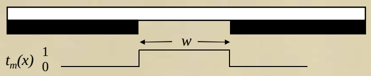
Fraunhofer Diffraction

- In the far field, the electric field of the diffraction pattern $T_m(f_x,f_y)$ is the *Fourier Transform* of the mask transmittance $t_m(x,y)$.

$$T_m(f_x,f_y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} t_m(x,y)\exp\left(-2\pi i(f_x x + f_y y)\right)dx\,dy$$

- This is the basis of Fourier Optics.

Isolated Space – Do the Math



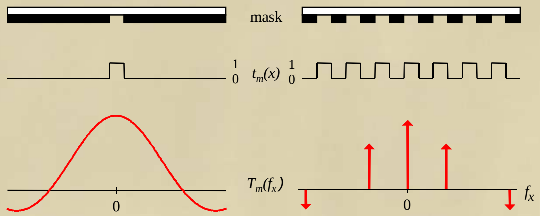
$$T_m(f_x) = \int_{-\infty}^{\infty} t_m(x) e^{-i2\pi f_x x}\,dx = \int_{-w/2}^{w/2}(1)e^{-i2\pi f_x x}\,dx$$

$$T_m(f_x) = \left.\frac{e^{-i2\pi f_x x}}{-i2\pi f_x}\right|_{-w/2}^{w/2} = \frac{1}{-i2\pi f_x}\left(e^{-i\pi f_x w} - e^{i\pi f_x w}\right)$$

Euler's Identity $\sin(x) = \dfrac{e^{ix} - e^{-ix}}{2i}$ ➞ $T_m(f_x) = \dfrac{\sin(\pi f_x w)}{\pi f_x}$

Diffraction

Note: masks not drawn to scale.



Isolated space

$$T_m(f_x) = \mathcal{F}\{t_m(x)\} = \frac{\sin(\pi w f_x)}{\pi f_x}$$

Repeating lines and spaces

$$T_m(f_x) = \frac{1}{p}\sum_{n=-\infty}^{\infty}\frac{\sin(\pi w f_x)}{\pi f_x}\delta\left(f_x - \frac{n}{p}\right)$$

Lecture 41: What have we Learned?

- Define “diffraction-limited imaging”
- What is a “spatial frequency”?
- Explain Huygens’ Principle
- How does one calculate the Fraunhofer diffraction pattern from a mask?

