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

Lecture 44
Lithography: Projection Imaging, part 2

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Image Example: equal lines and spaces

Let p = 250 nm, NA = 0.93, λ = 193 nm:
How many diffraction orders will go through the lens?

$$\frac{N_{max}}{p} \le \frac{NA}{\lambda}$$

Answer: $N_{max} = 1$

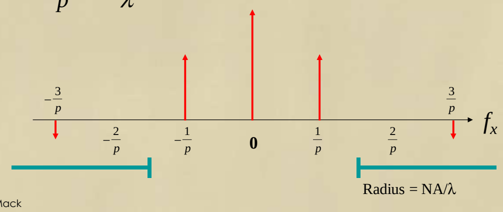


Image Example: equal lines and spaces

$$T_m(f_x) = \sum_{n=-\infty}^{\infty} a_n \delta\left(f_x - \frac{n}{p}\right), \quad a_n = \frac{\sin(n\pi/2)}{n\pi}$$

$$P(f_x)T_m(f_x) = \frac{1}{\pi}\delta\left(f_x + \frac{1}{p}\right) + \frac{1}{2}\delta(f_x) + \frac{1}{\pi}\delta\left(f_x - \frac{1}{p}\right)$$

-1st order   0th order   +1st order

Now, take the inverse Fourier Transform…

Image Example: equal lines and spaces

From the Fourier Transform table: $F^{-1}\{\delta(f_x)\} = 1$

A point in the diffraction pattern produces a plane wave at the wafer.

Applying the shift theorem:

$$F^{-1}\{\delta(f_x - f')\} = e^{i2\pi f' x}$$

A point shifted from the center of the lens produces a tilted plane wave at the wafer.

Image Example: equal lines and spaces

$$P(f_x)T_m(f_x) = \frac{1}{\pi}\delta\left(f_x + \frac{1}{p}\right) + \frac{1}{2}\delta(f_x) + \frac{1}{\pi}\delta\left(f_x - \frac{1}{p}\right)$$

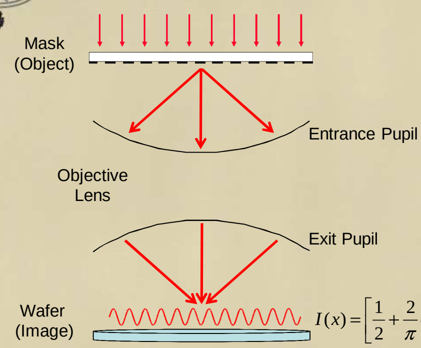
$$E(x) = F^{-1}\{PT_m\} = \frac{1}{\pi}e^{-i2\pi x/p} + \frac{1}{2} + \frac{1}{\pi}e^{i2\pi x/p}$$

(three plane waves interfering)

Applying Euler's identity:

$$E(x) = F^{-1}\{PT_m\} = \frac{1}{2} + \frac{2}{\pi}\cos(2\pi x/p)$$

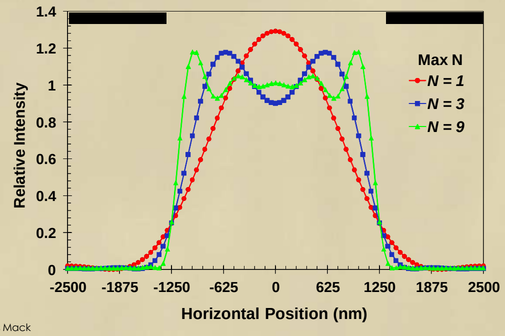
Image Example: equal lines and spaces



$$I(x) = \left[\frac{1}{2} + \frac{2}{\pi}\cos(2\pi x/p)\right]^2$$

Coherent Image vs. Number of Diffraction Orders

(equal lines and spaces)



Imaging Review

- *The numerical aperture* defines the range of diffracted angles that can pass through the lens (and thus the maximum spatial frequency is NA/λ)
- The *imaging lens* produces an image, at the focal plane, that is equal to the Fourier Transform of the portion of the diffraction pattern that passes through the lens
- Since only the portion of the diffraction pattern entering the lens is used to form the image, lost diffracted light results in a degraded aerial image

Lecture 44: What have we Learned?

- How can you determine which diffraction orders make it through the lens?
- Can you take the inverse Fourier transform of a sum of delta functions (diffraction orders)?
- A point of light (diffraction order) at the lens produces what type of wave at the wafer?
- What happens to the image if the lens captures more diffraction orders?