Outline:

- Intro to lithography:
  - Shadow & projection printing
  - Positive & Negative resists

- Clear rooms

- Diffraction-limited resolution
  - double-slit $\Rightarrow W = \frac{L \lambda}{d}$
  - Aperture
  - Lns:
    - Resolution
    - DOF

- Masks
  - Registration
  - Resolution Envelope
- Review of Diffusion: \( L = \sqrt{D t} \)

- Course Map: Lithography of \( L \), resists
  * Stencil/mask & e-beam, litho contact.

- Pattern transfer from Mask to Photomask:
  * Three performance-related parameters:
    1. Resolution - min. feature size
    2. Registration - measure how accurately patterns on successive masks can be aligned
    3. Throughput - number of wafers/devices/time

- Two Optical Exposure Routes:
  1. Shadow Printing (Glass mask or transparency)
  2. Projection Printing (Steppers)

- The need for clean rooms:
  * 1 dust particle on mask can lead to failure of all devices.
  "Class" rating:
  - Class 100: 100 particles/ft\(^2\) that are > 0.5 \( \mu \)m
  - Air is class \( 10^6 \)
  - \( M \)-class: \( 10^M / \text{ft}^2 \), \( M = \frac{10 \text{ ppm}}{\text{m}^3} \)
200 mm water is exposed for 1 minute to air stream @ 30 m/min; how many particles? 

\[ \text{Class B } \approx 10 \text{ particles/ft}^3 = 350 \text{ m}^3 \text{; volume of air in 1 min is } \frac{30 \text{ m}}{\text{min}} \times \left( \frac{0.33 \text{ ft}}{2} \right)^2 \times 1 \text{ min} = 0.84 \text{ m}^3 \approx 330 \text{ particles.} \]

Resolution Limits → the Diffraction Limit:

\[ E(x,t) = E_0 \exp \left( i \left( \Delta x - \omega t \right) \right) \]

\[ = E_0 \exp \left( i \phi(x,t) \right) \]

If 400 chips, there is almost 1 dust particle per chip!!

Luckily, most don't stick.

\[ \lambda = \frac{2\pi}{n} \]

\[ \text{Simplest Interference:} \]

\[ I = (E_1 e^{i\phi_1} + E_2 e^{i\phi_2}) \cdot (E_1 e^{-i\phi_1} + E_2 e^{-i\phi_2}) \]

\[ = E_1^2 + E_2^2 + E_1 E_2 e^{i(d_1 - d_2)} + E_1 E_2 e^{-i(d_1 - d_2)} \]

\[ = E_1^2 + E_2^2 + 2E_1 E_2 \cos(d_1 - d_2) \]

\[ \text{Interference term brightest when } d_1 - d_2 = n \lambda \]
Diffraction & Interference affect pattern transfer

When wafer & mask are close together, "near-field" and Fraunhofer diffraction

Fresnel
Fraunhofer
The main results of diffraction-limited lithography can be understood from the double-slit experiment:

Find an expression for the interference pattern a distance $L$ from the two slits:

Constructive interference occurs between two rays when path-length difference

is an integral multiple of the wavelength $\lambda$:

$$\delta = m \cdot \lambda \quad \text{where} \quad m \in \mathbb{Z}$$

but $\frac{S}{d} = \sin \theta$, so

$$S = d \sin \theta$$

$$\frac{S}{d} = \frac{d \sin \theta}{d} = \frac{dy}{L}$$

For constructive interference:

$$y = \frac{m \cdot L \cdot \lambda}{d}$$

For destructive interference:

$$y = \frac{m \cdot L \cdot \lambda}{2d}$$
The diffraction through a single slit (not two small slits) can be found in a similar way and yields:

\[ W = \frac{2\lambda}{d} \]

\[ \Delta \theta = \frac{2\lambda}{d} \]

For contact printing, we want \( W \approx D \), so \( W^2 = 2\lambda \Rightarrow W \approx \sqrt{2\lambda} \)

\[ \Delta \theta = \frac{1.22 \lambda}{D} \Rightarrow W = \frac{1.22 \lambda}{D} \]

Circular slit (Airy Disk)

#### Rayleigh's Criterion for just-resolvable diffraction pattern:

\[ X_{\text{min}} = f \Delta \theta = \frac{\lambda}{N.A.} \]

where \((\frac{f}{\theta})^{-1} \approx N.A. = n \sin \theta\)

\[ X_{\text{min}} = K \frac{\lambda}{N.A.} \]

determined by process & optical aberrations, in imperfections, can play tricks to make smaller.
So the resolution is just \( x_{\text{res}} \):

\[
\lambda_x = \frac{\lambda}{N.A.}
\]  

\[
\text{(Resolution)}
\]

The depth-of-field is:

\[
\text{DOF} = \frac{\left(\frac{\lambda}{2}\right)}{\tan \theta}
\]

\[
= \frac{\lambda - \frac{1}{2}}{\sin \theta}
\]

\[
= \frac{K_1 D}{2 \times \text{N.A.}} \cdot \frac{\lambda}{n \sin \theta}
\]

\[
= \frac{K_1 n}{2} \cdot \frac{\lambda}{(\text{N.A.})^2}
\]

\[
\text{(Depth-of-focus)}
\]

Show N.S.

In order to make viable devices (name of the game),

we want to reduce \( \lambda \) while keeping DOF relatively high.

If N.A. \( \to \infty \), then DOF \( \to 0 \) really fast, so need only flat surface.
So generally, the route is to decrease $\eta$:

$436 \text{ nm} \rightarrow 365 \text{ nm} \rightarrow \text{ F}_2 \text{ laser} \rightarrow 248 \text{ nm}$

$6\text{-line} \rightarrow 157 \text{ nm (7.9 eV!!)}$

$7\text{-line}$

$\text{F}_2 \text{ laser}$

$E_0 \text{ of SiO}_2 \text{ 8.9 eV}$