Diffraction (1)

- A simple example is the image formed by a small circular aperture (Airy disk).
- Note that a point image is formed only if:
  - $\lambda \to 0$, $d \to \infty$, or $f \to 0$

\[ R = \frac{1.22\lambda \cdot f}{d} \]

- Diffraction is usually described in terms of two limiting cases:
  - Fresnel diffraction - near field (proximity and contact systems)
  - Fraunhofer diffraction - far field (projection systems)
Resolution

- The denominator is defined as the numerical aperture:
  \[ \frac{NA}{n} \sin \alpha \]  
  Where \( \alpha \) represents the ability of the lens to collect diffracted light.

- The Resolution is then defined as
  \[ R = \frac{0.61 \lambda}{NA} + \frac{k_1 \lambda}{NA} \]  
  \( k_1 \) is an experimental parameter which depends on the lithography system and resist properties (\( \approx 0.4 - 0.8 \)).

- Obviously resolution can be increased by:
  - decreasing \( k_1 \)
  - Decreasing \( \lambda \)
  - increasing \( NA \) (bigger lenses)
Depth of Focus

• While resolution can be increased by:
  – decreasing $k_1$
  – Decreasing $\lambda$
  – increasing NA (bigger lenses)

\[
R = \frac{0.61 \lambda}{NA} = k_1 \frac{\lambda}{NA} \tag{4}
\]

• Higher NA lenses also decrease the depth of focus (DOF).
  (See text for derivation.)

\[
DOF = \delta = \pm \frac{\lambda}{2(NA)^2} = \pm k_2 \frac{\lambda}{(NA)^2} \tag{5}
\]

• $k_2$ is usually experimentally determined.

• Thus a 248nm (KrF) exposure system with a NA = 0.6 would have a resolution of $R \approx 0.3 \mu m$ ($k_1 = 0.75$) and a DOF of $\approx 0.35 \mu m$ ($k_2 = 0.5$).
**Proximity lithography.**

In proximity lithography, the mask is held above the substrate by a fixed distance or gap. (better protection for mask)

- Limiting factor: Fresnel diffraction
- General rule: resolution $\sim (g \lambda)^{0.5}$ where $g$ is gap.

*Derivation: Chang and Sze, ULSI Technology (McGraw Hill, 1996), p 274.*

Take $g = 20$ micron and $\lambda = 0.4$ micron: resolution $\sim 3$ micron.

Since it is difficult to maintain $g < 20$ micron, proximity lithography is rarely used in commercial production. Some versions are widely used in research and small scale production (Suss, 250 nm wavelength).