(1) Contact to source/drain of MOSFET.

Alignment error

“ideal”

“short”, ohmic contact
Solution: Design n+ region larger than contact hole
(2) Poly-Gate Overlap over FOX

"Ideal"

poly-gate

Fox

S/D implant

n⁺

Electrical short

"With alignment error"
Solution: Make poly gate longer to overlap the FOX
Total Overlay Tolerance

\[ \sigma^2_{total} = \sum_{i} \sigma_i^2 \]

\( \sigma_i \) = std. deviation of overlay error for \( i^{th} \) masking step  
\( \sigma_{total} \) = std. deviation for total overlay error

Layout design-rule specification should be \( > \sigma_{total} \)
Standing Waves

*Photoresist has a finite thickness

![Diagram of Standing Waves](image)

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Professor N. Cheung, U.C. Berkeley
Standing wave effect

Resist profile and energy deposition depend on oxide thickness underneath (see handout for derivation)

Intensity minima occur at: \( \frac{2\pi n}{\lambda} (d-x) = 0, \pi, 2\pi, \ldots \)

Intensity maxima occur at: \( \frac{2\pi n}{\lambda} (d-x) = \pi/2, 3\pi/2, 5\pi/2, \ldots \)
Intensity = minimum when \( x = d - m \frac{\lambda}{2n} \)  
\( m = 0, 1, 2, \ldots \)

Intensity = maximum when \( x = d - m \frac{\lambda}{4n} \)  
\( m = 1, 3, 5, \ldots \)

\( n = \) refractive index of resist

SiO\(_2\)/Si substrate
Simulated Resist Cross-section as function of development time

KTI 820 Resist

Dill Model
80 mJ/cm²

15s
30s
45s
60s
75s
Figure 7.24 Light from the exposed regions can be reflected by wafer topology and be absorbed in the resist in nominally unexposed regions.
Approaches for Reducing Substrate Effects

- Use absorption dyes in photoresist
- Use anti-reflection coating (ARC)
- Use multi-layer resist process
  1: thin planar layer for high-resolution imaging (imaging layer)
  2: thin develop-stop layer, used for pattern transfer to 3 (etch stop)
  3: thick layer of hardened resist (planarization layer)
Electron-Beam Lithography

\[ \lambda = \frac{12.3}{\sqrt{V}} \text{ Angstroms} \]
for \( V \) in Volts

Example: 30 kV e-beam
\[ \Rightarrow \lambda = 0.07 \text{ Angstroms} \]

NA = 0.002 – 0.005
Resolution < 1 nm

But beam current needs to be 10’s of mA for a throughput of more than 10 wafers an hour.
Low Throughput for both raster and vector scanning (Serial Process)
e-beam lithography

resolution factors

- beam quality \((\sim 1 \text{ nm})\)
- secondary electrons \((\text{lateral range: few nm})\)

performance records

organic resist PMMA \(\sim 7 \text{ nm}\)
inorganic resist, b.v. AlF\(_3\) \(\sim 1-2 \text{ nm}\)
The Proximity Effect

Monte Carlo simulation of electron trajectories

Figure 9-11  Small and large figures to be patterned with EBL requires position dependent dosage to compensate for proximity effects.
Figure 9.16  Basic schematic of an electron storage ring for XRL. Several exposure stations are indicated (after Glendenning and Cerrina, reprinted by permission, Noyes Publications).
X-Ray Proximity Printing

\[ \lambda \approx 10 \text{ Angstroms} \]

\[ l_m \propto \sqrt{\lambda g} \]
Figure 9.24  An x-ray projection lithography system using x-ray mirrors and a reflective mask (after Zorpette, reprinted by permission, © 1992 IEEE).
Alpha-Machine for EUV Lithography

<table>
<thead>
<tr>
<th>Specification</th>
<th>Beta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numerical Aperture</td>
<td>0.14</td>
</tr>
<tr>
<td>Demagnification Factor</td>
<td>4</td>
</tr>
<tr>
<td>Operating wavelength</td>
<td>11.2 nm</td>
</tr>
<tr>
<td>Resolution (assuming K1 = 0.5)</td>
<td>40 nm</td>
</tr>
<tr>
<td>Average Laser Power</td>
<td>1500 W</td>
</tr>
<tr>
<td>EUV flux to wafer</td>
<td>155 mw/cm²</td>
</tr>
<tr>
<td>Wafer Throughput (300mm wafers)</td>
<td>40 wph</td>
</tr>
</tbody>
</table>
Resist patterned by Extreme UV Lithography
Photo-Electron Scattering

Proximity Printing

Diffraction Limitation = $\sqrt{\lambda}$

Reduction Projection

Rayleigh Limitation = $\lambda$

Soft X-ray

Resolution ($\mu$m)

Exposure Wavelength (µm)
Immersion Lithography

A liquid with index of refraction $n > 1$ is introduced between the imaging optics and the wafer.

Advantages
1) Resolution is improved proportionately to $n$. For water, the index of refraction at $\lambda = 193$ nm is 1.44, improving the resolution significantly, from 90 to 64 nm.
2) Increased depth of focus at larger features, even those that are printable with dry lithography.
Drag a drop schemes also being considered by UTA.