Problem 1

\[ \Delta L = L \times \Delta T (\alpha_{\text{glass}} - \alpha_{\text{Si}}) \]

Maximum run in/out error = ± 1.0 \, \mu m with respect to the alignment marks on wafer => \( \Delta l = \pm 2 \, \mu m \) on photomask

\[ \therefore \Delta T_{\text{maximum}} = \frac{\pm 2 \times 10^{-4} \text{cm}}{20 \text{ cm} \times (9-2.3) \times 10^{-6}} = \pm 1.5^\circ \text{C} \]

Problem 2

The center only has translational errors: 0.5 \, \mu m along x, -0.5 \, \mu m along y.

After substracting the translational error, we have:

<table>
<thead>
<tr>
<th></th>
<th>Top</th>
<th>Right</th>
<th>Center</th>
<th>Left</th>
<th>Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>-0.5</td>
<td>+0.2</td>
<td>0</td>
<td>-0.2</td>
<td>+0.5</td>
</tr>
<tr>
<td>y</td>
<td>+0.2</td>
<td>+0.5</td>
<td>0</td>
<td>-0.5</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

The run out error is 0.2 \, \mu m

The rotational error is 0.5 \, \mu m (counter-clockwise)

Problem 3

(a) Example 1

For identical optical images, resist openings at the oxide/resist interface will have different sizes on thicker and thinner oxide regions. If the resist is used as the etching mask for oxide, we end up with different oxide feature sizes.

Photon Intensity due to standing wave

\[ \min \quad \text{min} \quad \min \]

\[ \max \quad \text{max} \quad \text{max} \]
Example 2

After development

- cross-section is schematic only

(b) (1) Light reflection from the slope can cause local increase of exposure which leads to linewidth variation during resist development. ARC reduces this reflection.

Substrate

(2) Less reflected beam gives less standing wave effect, which gives also less variation of linewidth.
(3) Resist has more uniform thickness due to ARC layer planarization. The required development time can be more uniform. Less linewidth variation also.

Problem 4

From \( k \cdot \frac{0.436}{(0.436/NA)} = 0.5 \) and \( 0.436/\left[2(NA)^2\right] = 1 \), we obtain \( NA = 0.467 \) and \( k = 0.536 \)

For Stepper A: \( R = 0.536 \cdot 0.365 / 0.6 = 0.326 \text{um} - \) does not meet R requirement
\( \text{DOF} = 0.365/\left[2 \cdot (0.6)^2\right] = 0.507 \text{um} > 0.4 \text{um} – \text{o.k.} \)

For Stepper B: \( R = 0.536 \cdot 0.248 / 0.5 = 0.266 \text{um} - \text{o.k.} \)
\( \text{DOF} = 0.248/\left[2 \cdot (0.5)^2\right] = 0.496 \text{um} > 0.4 \text{um} - \text{o.k.} \)

Only Stepper B will meet both R and DOF requirements.
Problem 5
(a) The resist has infinite contrast.
(b) (i)

Problem 6
(a)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Desired Value (High, Low, or Depends)</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda$/NA</td>
<td>Depends</td>
<td>Low $\lambda$/NA gives smaller printable feature but decreases DOF</td>
</tr>
<tr>
<td>Aerial Image contrast</td>
<td>High</td>
<td>Features still printable even with less resist contrast</td>
</tr>
<tr>
<td>Slope of aerial image intensity versus position</td>
<td>High</td>
<td>Steeper slope for developed resist pattern</td>
</tr>
<tr>
<td>Resist Contrast</td>
<td>High</td>
<td>Steeper slope for developed resist pattern</td>
</tr>
<tr>
<td>Resist Sensitivity</td>
<td>High</td>
<td>Higher throughput</td>
</tr>
<tr>
<td>Resist optical absorption coefficient</td>
<td>Depends</td>
<td>High absorption reduces standing wave and proximity scattering effects. However cannot be too high to block photon penetration of bottom of resist.</td>
</tr>
</tbody>
</table>
(b) E-beam lithography

**Advantage:** Very small beam spot ( < 1nm), can define very small features. [However, the smallest feature patternable still is limited by electron scattering effects].

**Disadvantages:**
Low throughput – a serial writing process versus the parallel writing process of optical lithography.
Proximity effect- Backscattered electrons from substrate material may affect critical feature size.