Problem: Resist Feature Collapse

- Resist features collapse upon formation at high aspect ratios.
- What are important parameters controlling this phenomena?
- What is required to design around this problem?
Shear and Bending Model

- Beam is treated as elastic solid

\[ EI_y \frac{d^4v}{dz^4} = \Delta PL \]

- Young-Laplace pressure

\[ \Delta P = \gamma \nabla \cdot n = \frac{\gamma}{R} \]

- Aspect Ratio

\[ \varepsilon = \frac{\text{Thickness}}{\text{HalfPitch}} \]

![Diagram showing a beam with shear and bending forces.]
• Shear Stress is linear with $\varepsilon$

$$\tau_{xy} = \Delta P (\varepsilon - \frac{2z}{P})$$

• Tensile stresses is quadratic in $\varepsilon$

$$\sigma_z = \frac{M_y}{I_y} x = \frac{48 \Delta Px z^2}{P^3}$$

$$\sigma_{\text{max}} = 12 \frac{\gamma}{P} \varepsilon^2$$
Perturbation in Spacing

- Stress field in resist beam causes deformation

\[ \nu_{\text{max}} = 3\varepsilon^4 \frac{\gamma}{E} \]

- Deformation influences Laplace pressure

\[ \Delta P = \frac{4\gamma}{P - \nu_{\text{max}}} \]
An Illustrative Example
Perturbation in Spacing Cont.

- Updated Laplace pressure gives new elastic problem.
- Several iterations reveals a series convergence for deformation and stress.
- Note: Rigid Model is recovered in limit \( E \rightarrow 8 \)

\[
\nu_{\text{max}}^{(i)} = 3\varepsilon^4 \frac{\gamma}{E} \sum_{m=0}^{i} \left(-6\varepsilon^4 \frac{\gamma}{EP}\right)^m
\]

\[
\sum_{m=0}^{\infty} (-x)^m = x + 1
\]

\[
\sigma_{\text{max}} = 12 \frac{\gamma}{P} \varepsilon^2 \left( 1 - \frac{3\varepsilon^4 \gamma}{PE} - \frac{18\varepsilon^8 \gamma^2}{P^2 E^2} \right)
\]
Feature Collapse Comparison

- Consider the system
  - \( E \sim 10^9 \text{ Pa} \)
  - \( \gamma \sim 70 \text{ mJ/m}^2 \)
- High stresses cause adhesive or plastic deformation failure, thus critical aspect ratio exists for each pitch.
Conclusions

- Elastic deformation is important in considering failure of resist beams
  - Rigid model significantly overestimates stable region

\[ N_{Ta} = \frac{\varepsilon^4 \gamma}{PE} = \frac{\text{Deformation \_ scale}}{\text{Feature \_ scale}} \]

- Length scale for deformation is \( \gamma/E\varepsilon^4 \approx 0.07\varepsilon^4 \text{nm} \) for glassy polymer/H\textsubscript{2}O

- Supercritical develop would eliminate interfacial tension induced failure