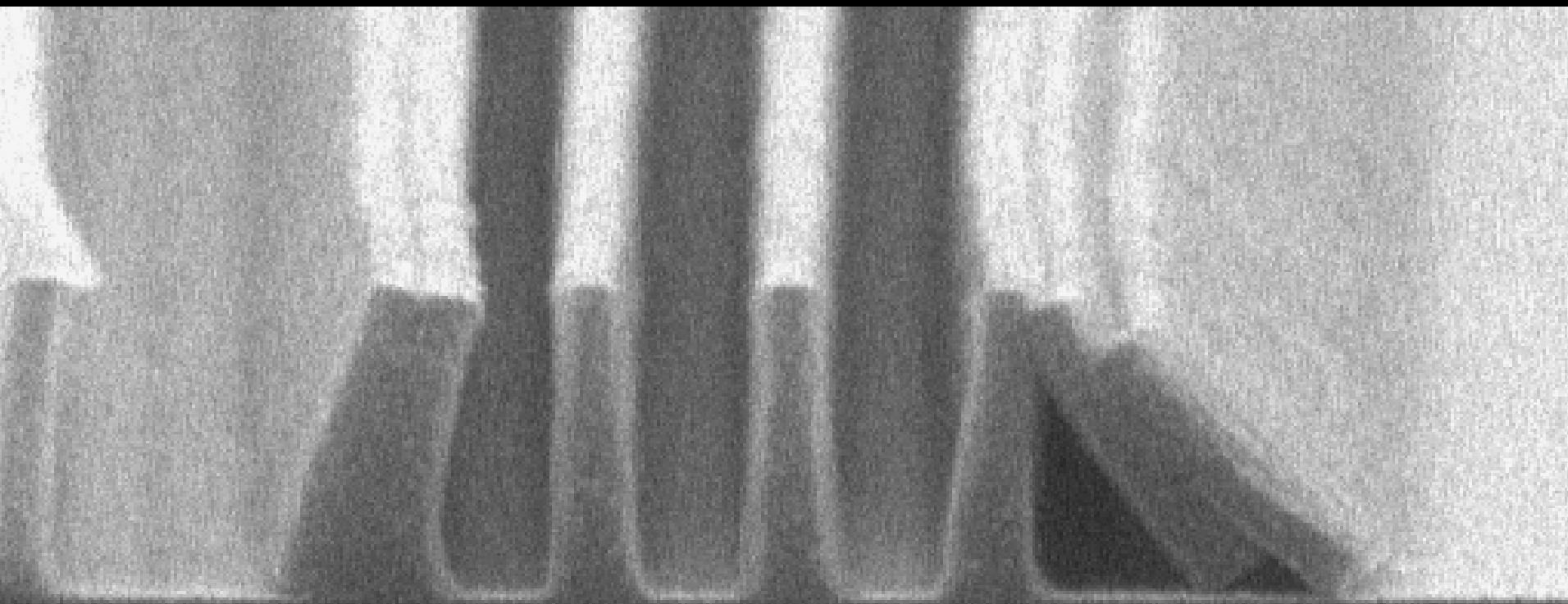
Failure Analysis of Resist Pattern Collapse: Surface Tension Influences



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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

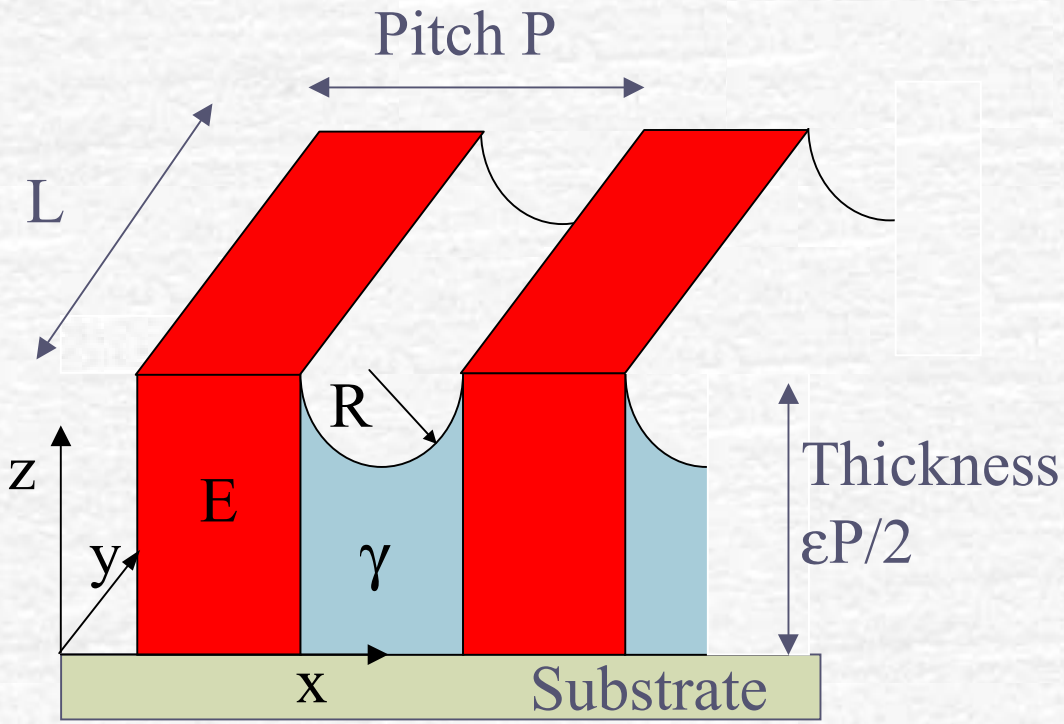
$$EI_y \frac{d^4 v}{dz^4} = \Delta PL$$

- Young-Laplace pressure

$$\Delta P = \gamma \nabla \cdot \underline{n} = \frac{\gamma}{R}$$

- Aspect Ratio

$$\varepsilon = \frac{Thickness}{HalfPitch}$$



$$I_y = \frac{LP^3}{96}$$ Moment of Inertia

$$M_y = \Delta PL \frac{z^2}{2}$$ Bending Moment

Shear and Bending Model Cont.

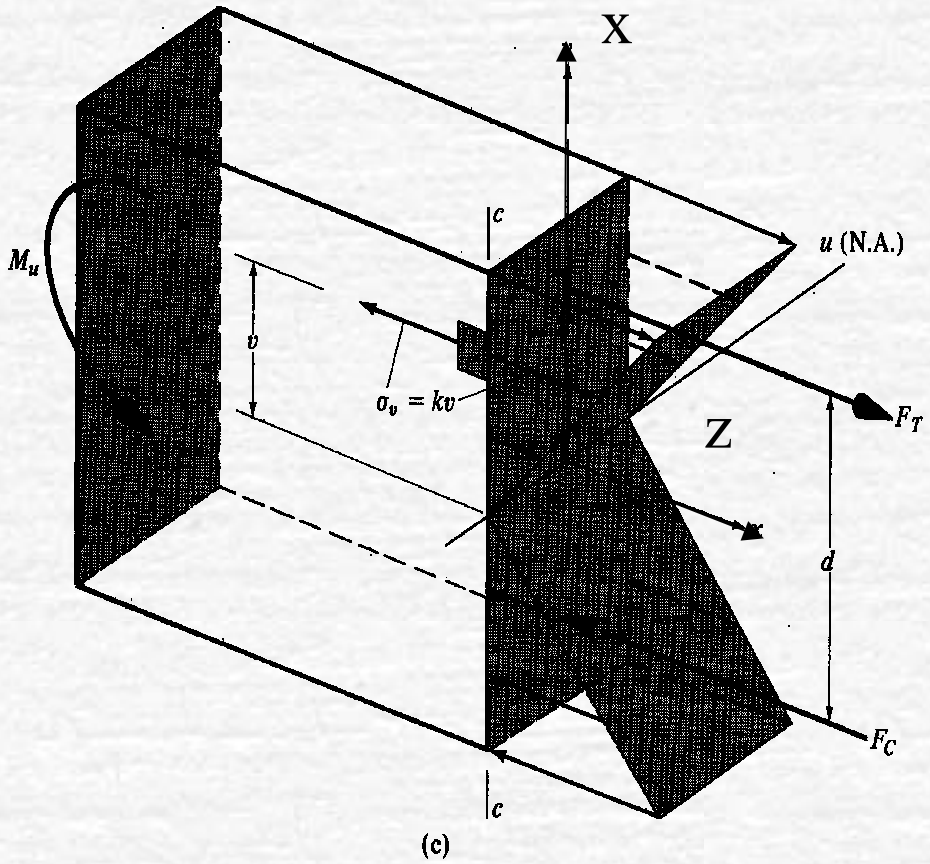
- Shear Stress is linear with ε

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

- Tensile stresses is quadratic in ε

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

$$\sigma_{\max} = 12\frac{\gamma}{P}\varepsilon^2$$



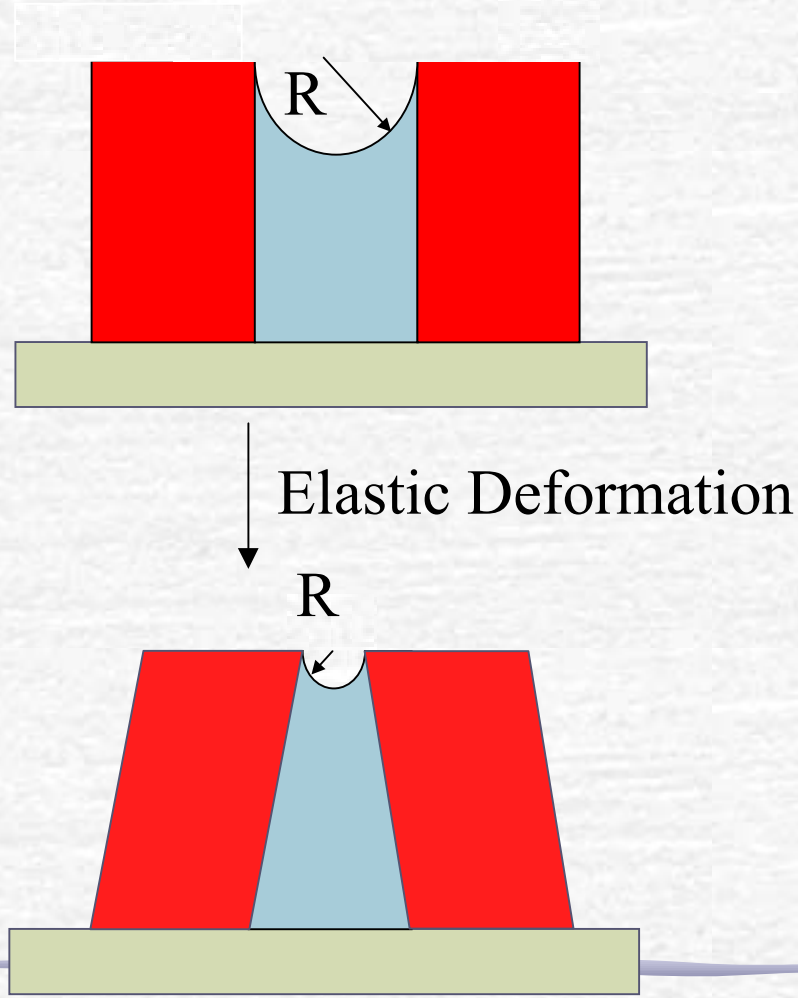
Perturbation in Spacing

- Stress field in resist beam causes deformation

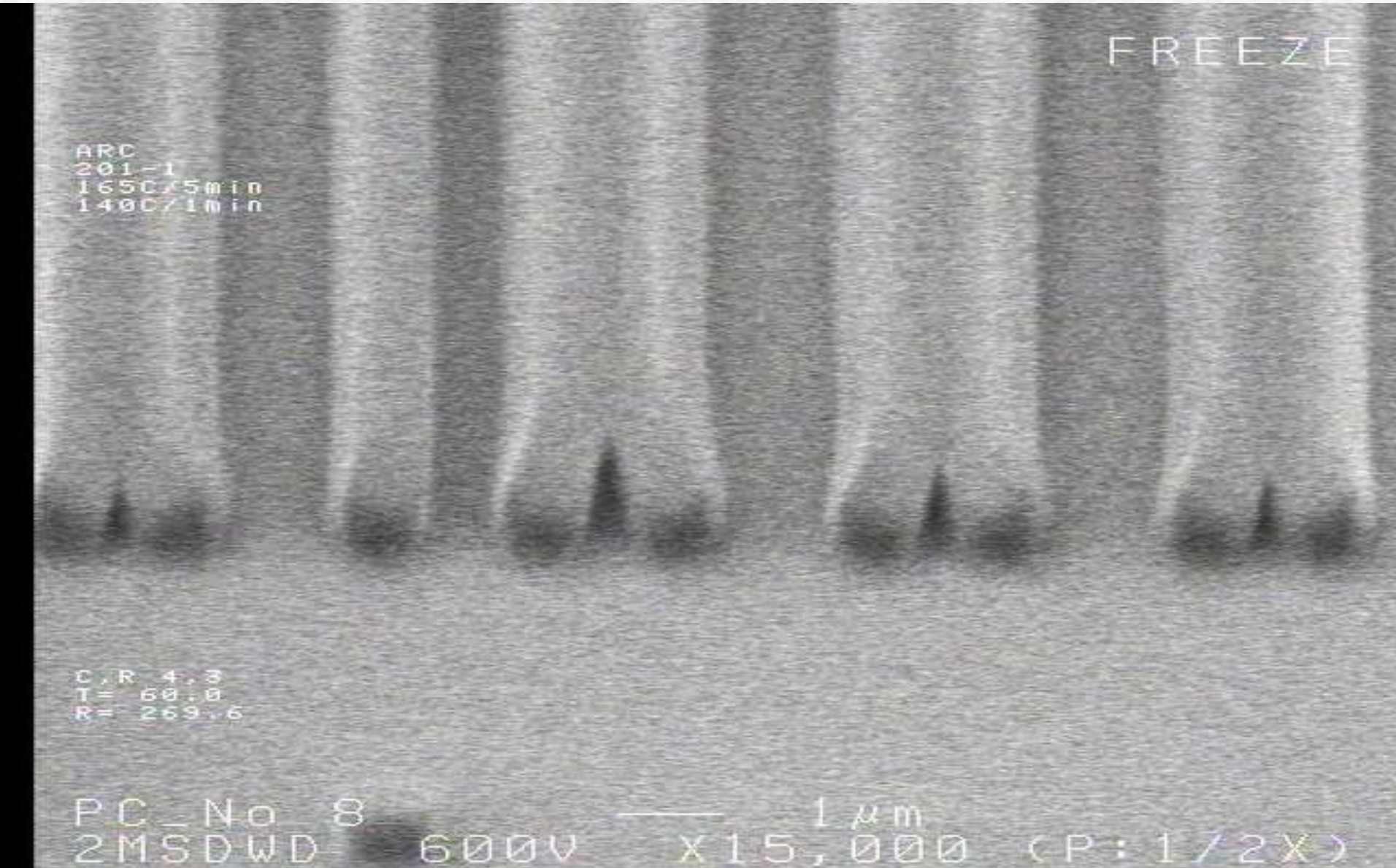
$$v_{\max} = 3\varepsilon^4 \frac{\gamma}{E}$$

- Deformation influences Laplace pressure

$$\Delta P = \frac{4\gamma}{P - v_{\max}}$$



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→8

$$v_{\max}^{(i)} = 3\varepsilon^4 \frac{\gamma}{E} \sum_{m=0}^{i} \left(-6\varepsilon^4 \frac{\gamma}{EP} \right)^{-m}$$

$$+$$

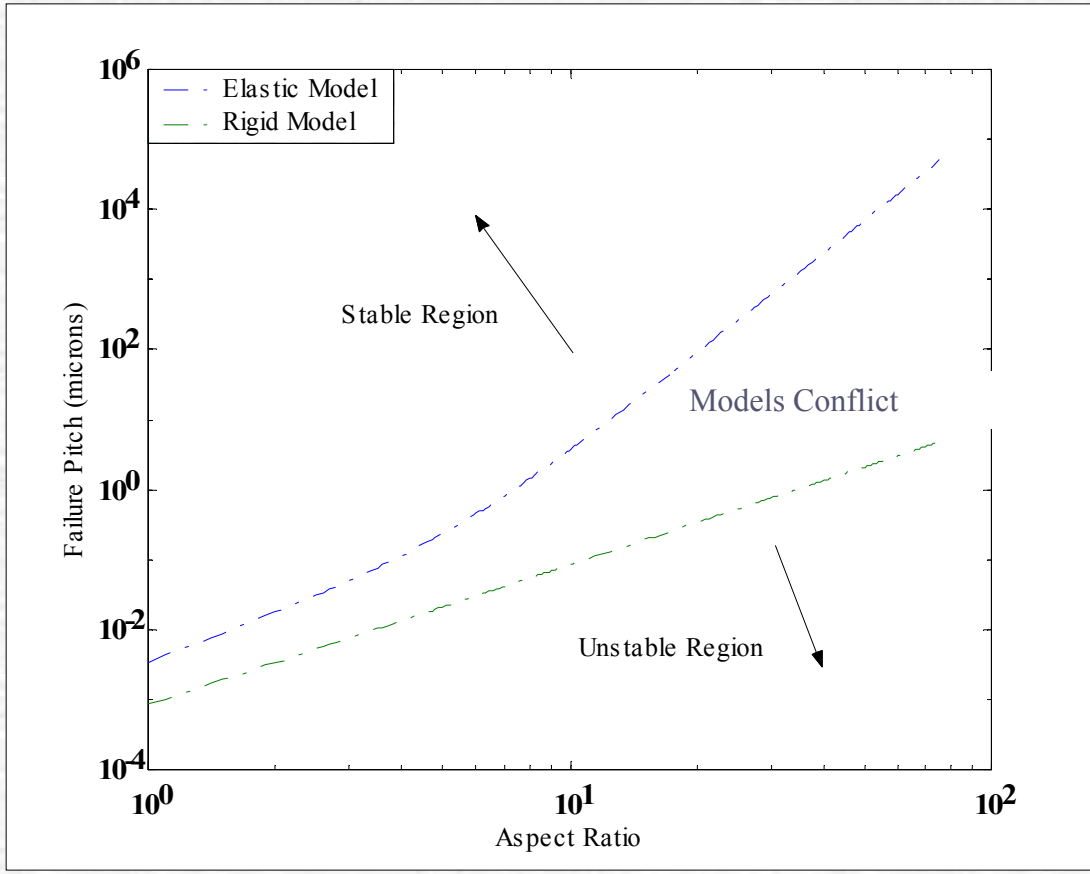
$$\sum_{m=0}^{\infty} (-x)^{-m} = x + 1$$

$$\sigma_{\max} = 12 \frac{\gamma}{P} \varepsilon^2 \left(\frac{1}{1 - \frac{3\varepsilon^4 \gamma}{PE} - \frac{18\varepsilon^8 \gamma^2}{P^2 E^2}} \right)$$

Feature Collapse Comparison

- Consider the system
  - $E \sim 10^9$ Pa

    $\gamma \sim 70$ 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
  - $N_{Ta} = \frac{\varepsilon^4 \gamma}{PE} = \frac{Deformation\_scale}{Feature\_scale}$
- Length scale for deformation is $\gamma/E\varepsilon^4 \sim 0.07\varepsilon^4$nm for glassy polymer/$H_2O$
- Supercritical develop would eliminate interfacial tension induced failure