

Challenges Associated with Line Pattern Collapse for EUV Lithography

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TOKYO ELECTRON

Outline

- **Introduction**
- **Line pattern collapse – The Critical Parameters**
- **Continued scaling of resist thickness?**
- **Modification of resist or processing**
 - Resist modulus
 - Surface tension
 - Contact angle
- **Summary**

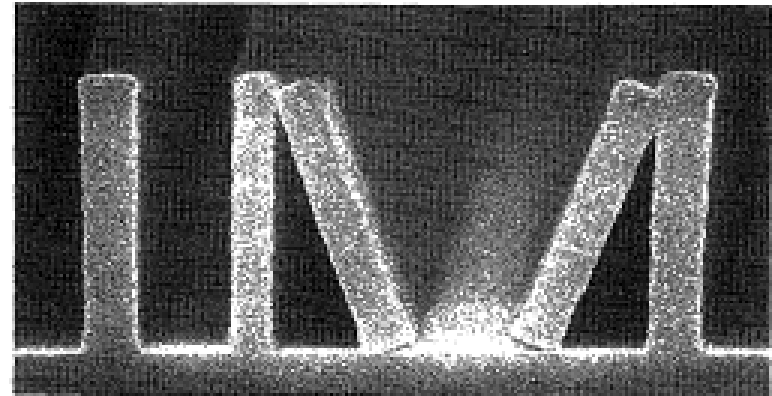
Line Pattern Collapse

Bending Failure



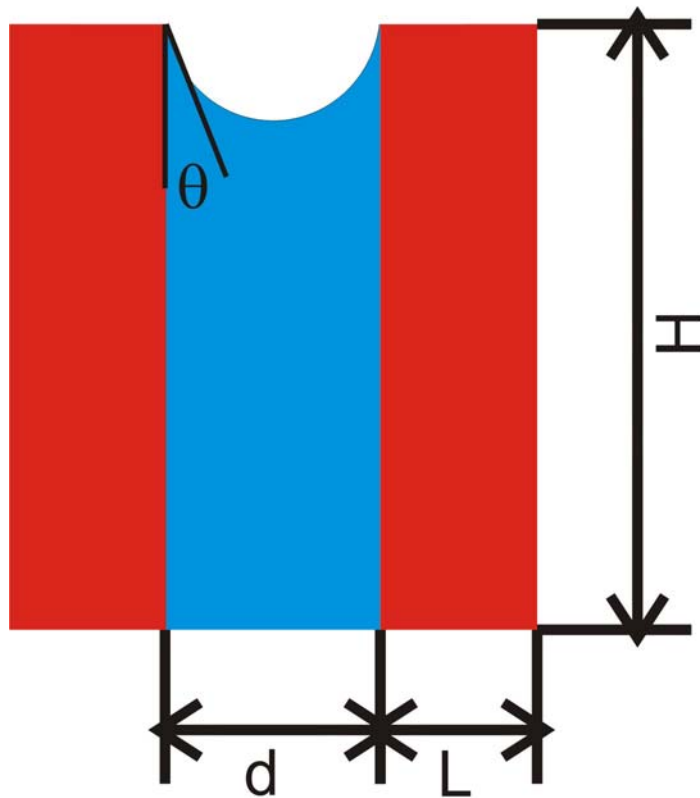
Capillary force exceeds the critical modulus of resist material.

Adhesion Failure



Capillary force exceeds the adhesive force between resist and substrate

Line Pattern Collapse – The Critical Parameters

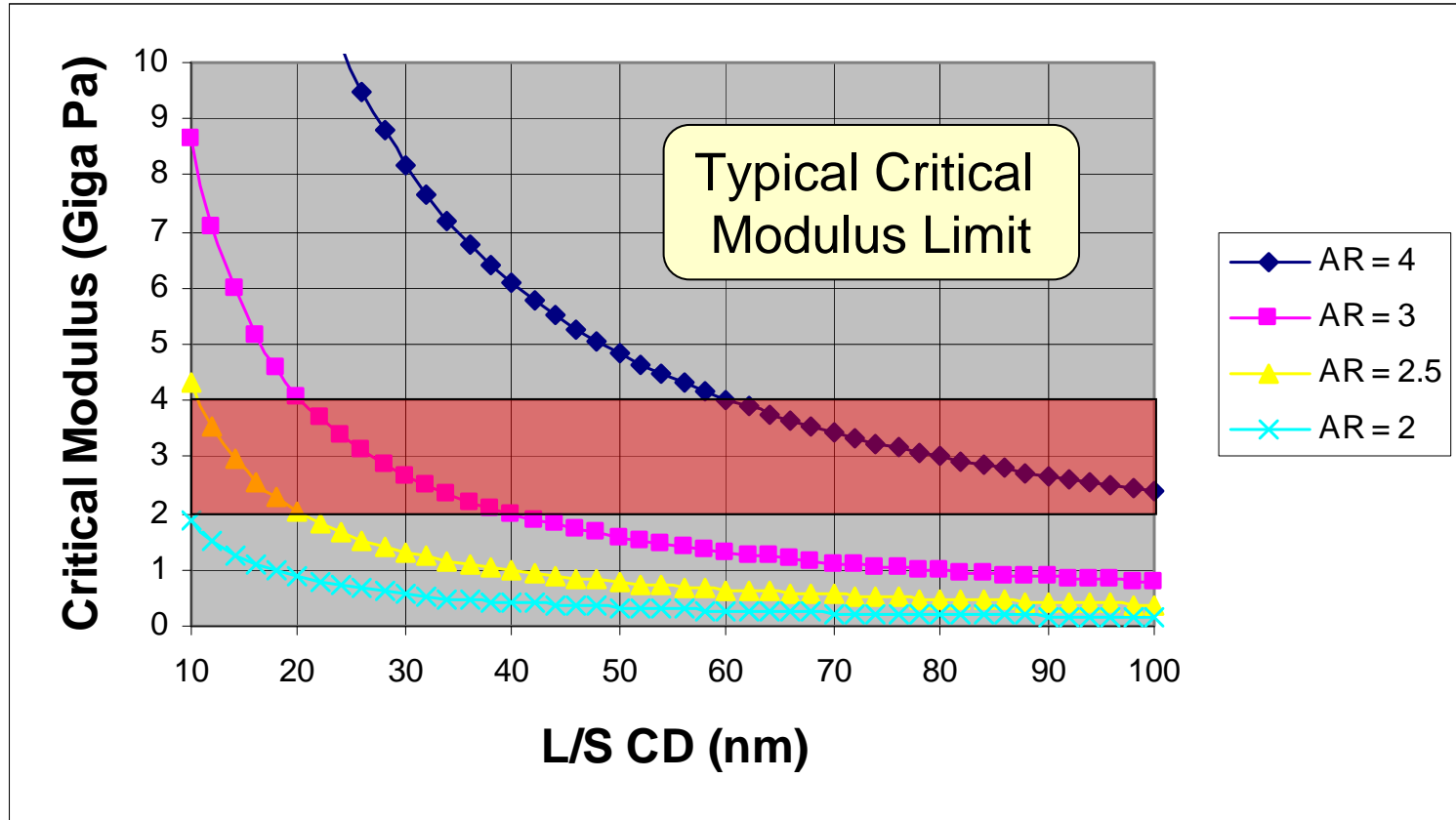


E_C = Critical Modulus
 d = Space Width
 L = Line Width
 H = Line Height
 θ = Contact Angle
 σ = Surface Tension

$$E_C = 4\sigma H^3 \left(\frac{3H \cos(\theta) + d \sin(\theta) + \sqrt{9H^2 \cos^2(\theta) + 6dH \sin(\theta) \cos(\theta)}}{L^3 d^2} \right)$$

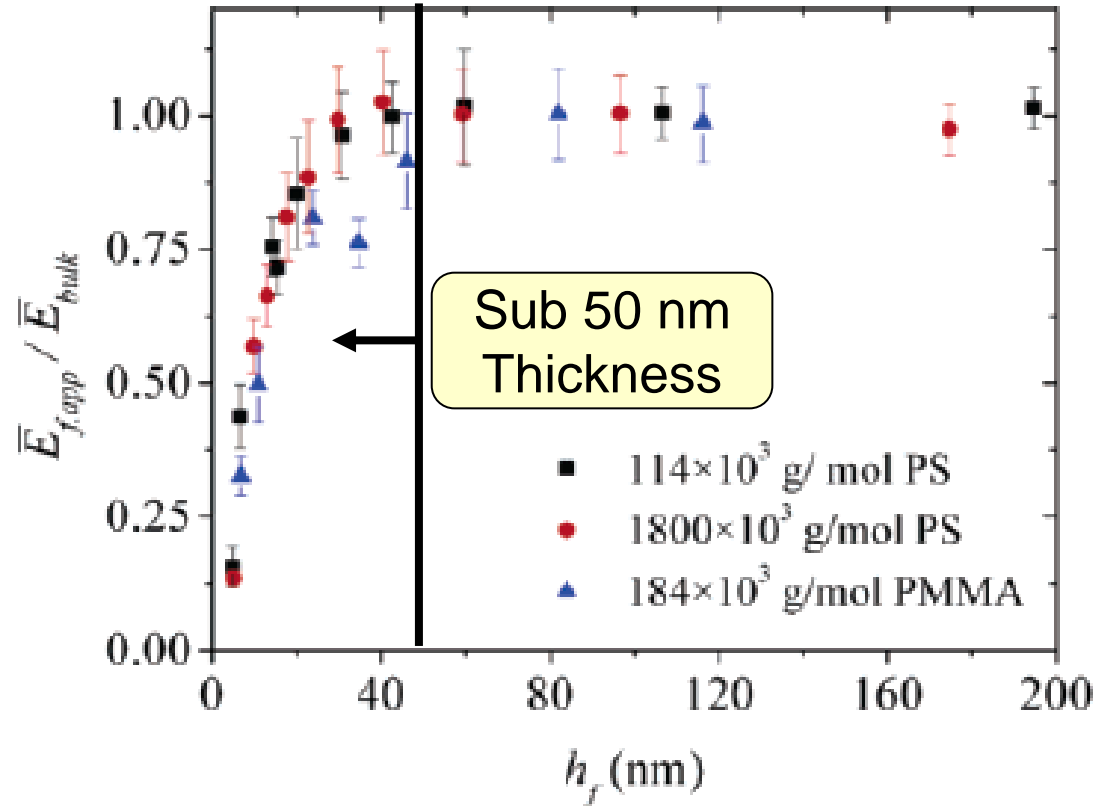
T. Tanaka, et al., Jpn J. Appl. Phys., Vol. 32 (1993) Pt. 1, No. 12B, pp. 6059

Critical Modulus of Collapse



Assumptions: $\sigma = 72 \text{ mN/m}$
 $\theta = 60 \text{ degrees}$

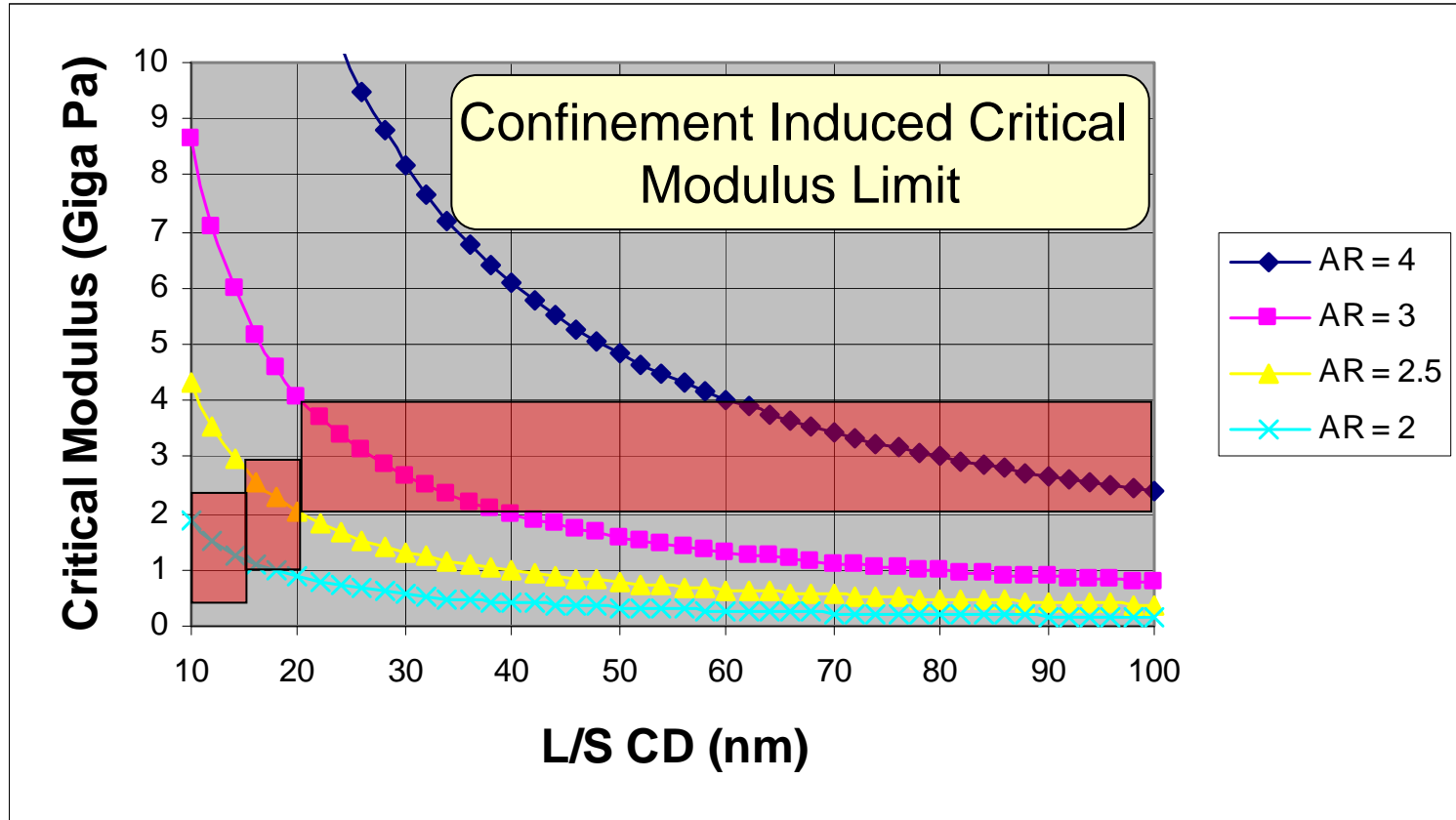
Thin Film Confinement Effects



Below 50 nm thickness modulus can reduce quickly

Stafford, et. Al., *Macromolecules*, 2006, 39, 5095-5099

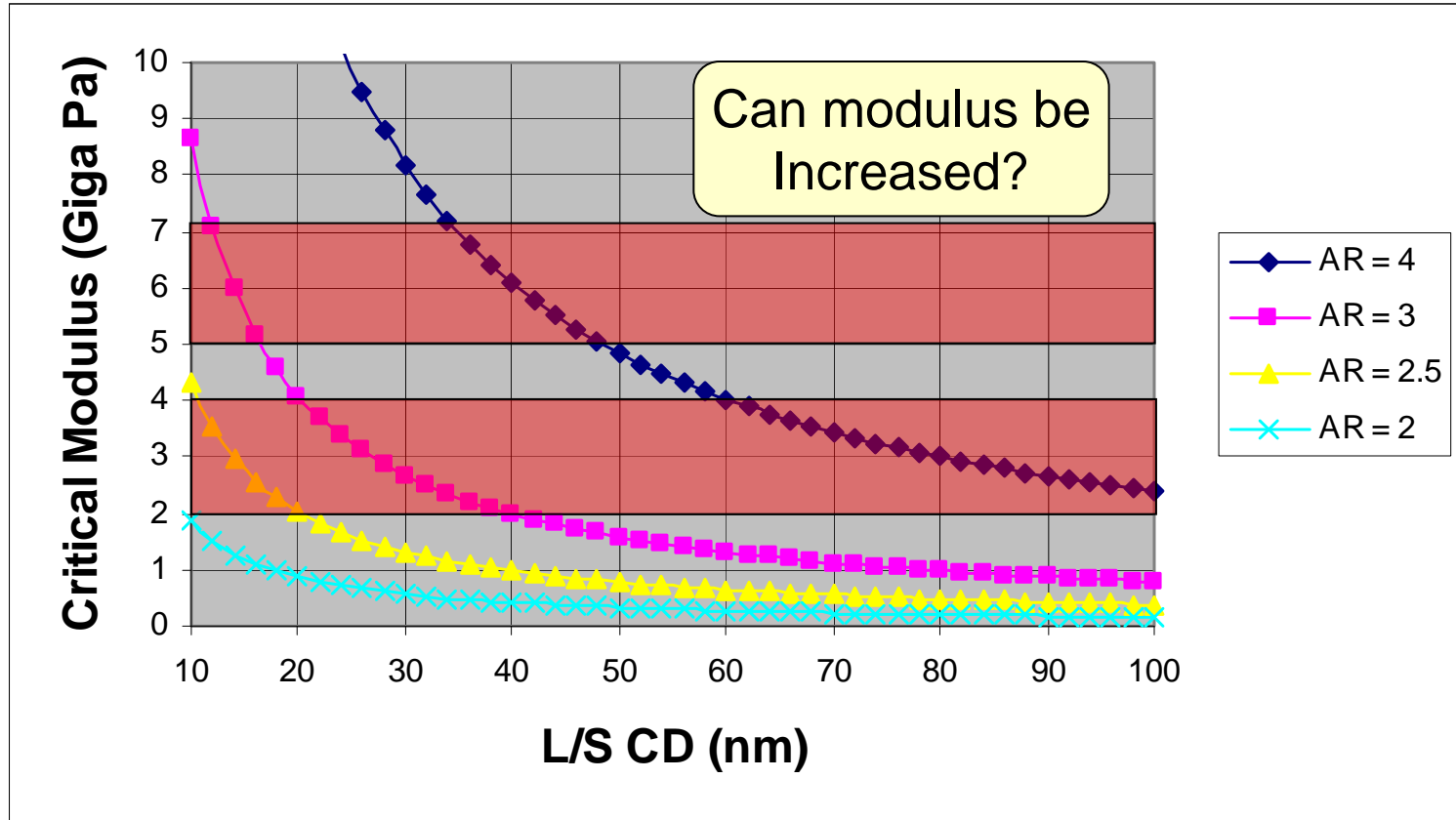
Confinement Induced Critical Modulus of Collapse



Assumptions: $\sigma = 72 \text{ mN/m}$
 $\theta = 60 \text{ degrees}$

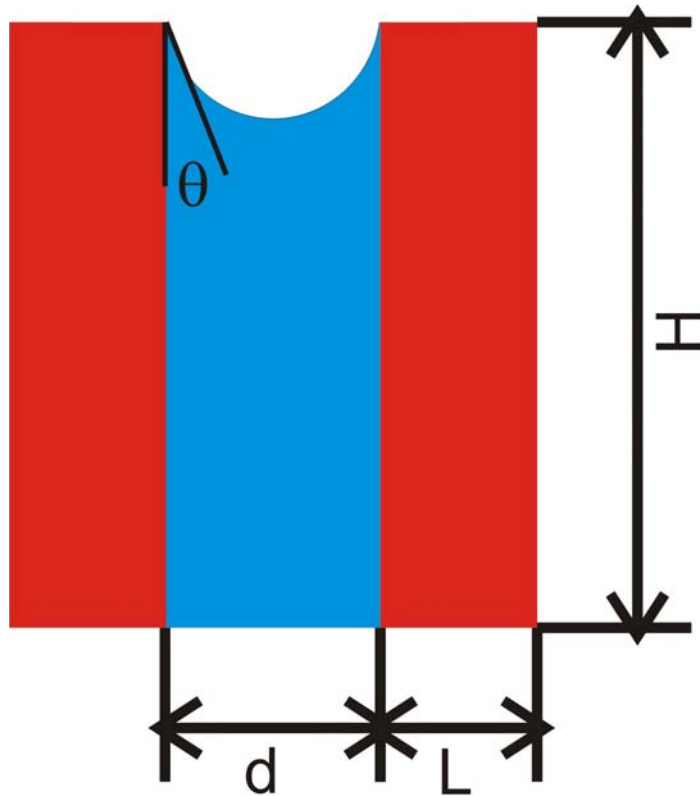
** Confinement Induced Critical Modulus Limit for Visualization only, it is not rigorously calculated

Increasing Critical Modulus of Collapse



Assumptions: $\sigma = 72 \text{ mN/m}$
 $\theta = 60 \text{ degrees}$

Line Pattern Collapse



E_C = Critical Modulus

d = Space Width

L = Line Width

H = Line Height

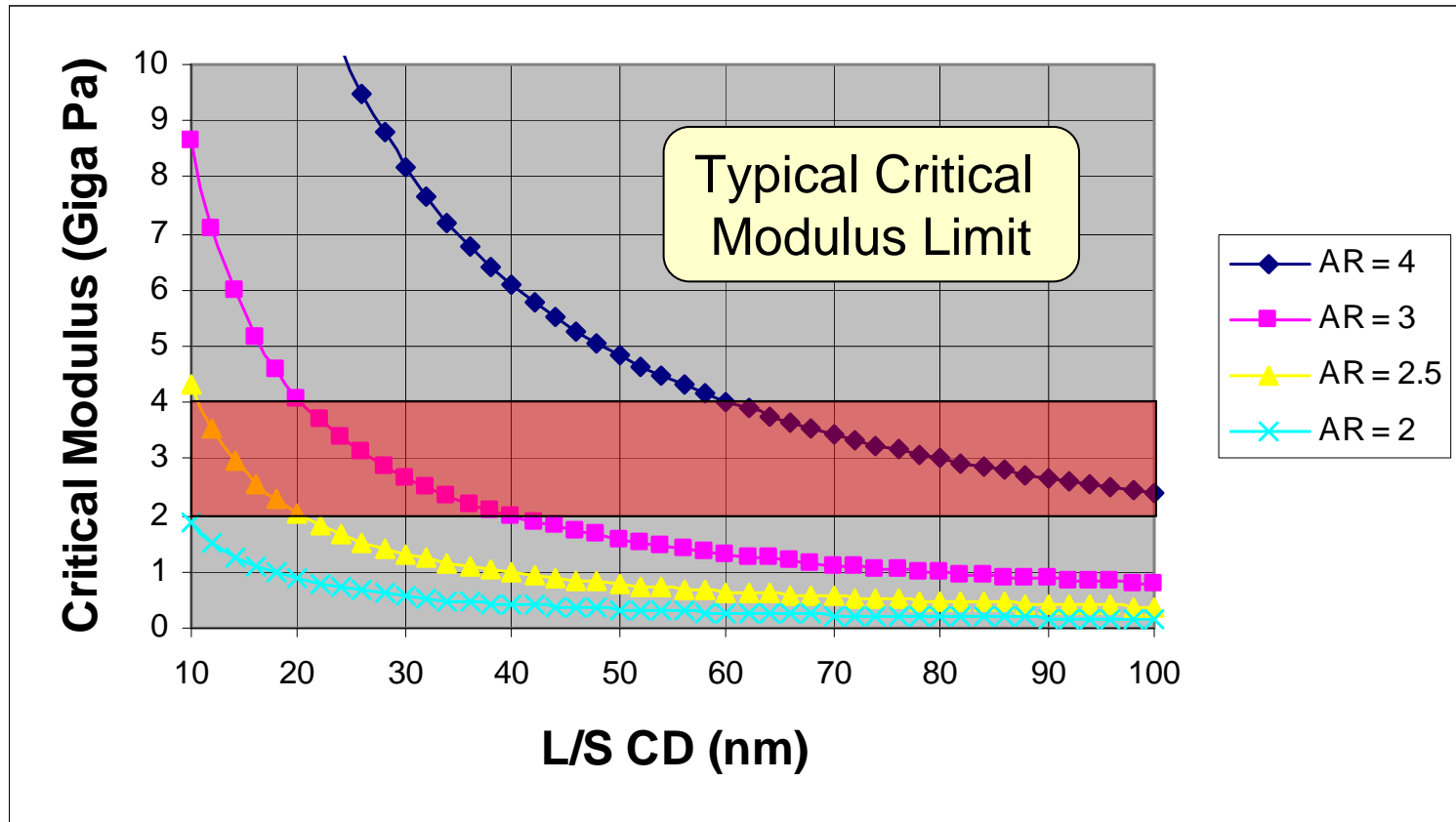
θ = Contact Angle

σ = Surface Tension

$$E_C = 4\sigma H^3 \left(\frac{3H \cos(\theta) + d \sin(\theta) + \sqrt{9H^2 \cos^2(\theta) + 6dH \sin(\theta) \cos(\theta)}}{L^3 d^2} \right)$$

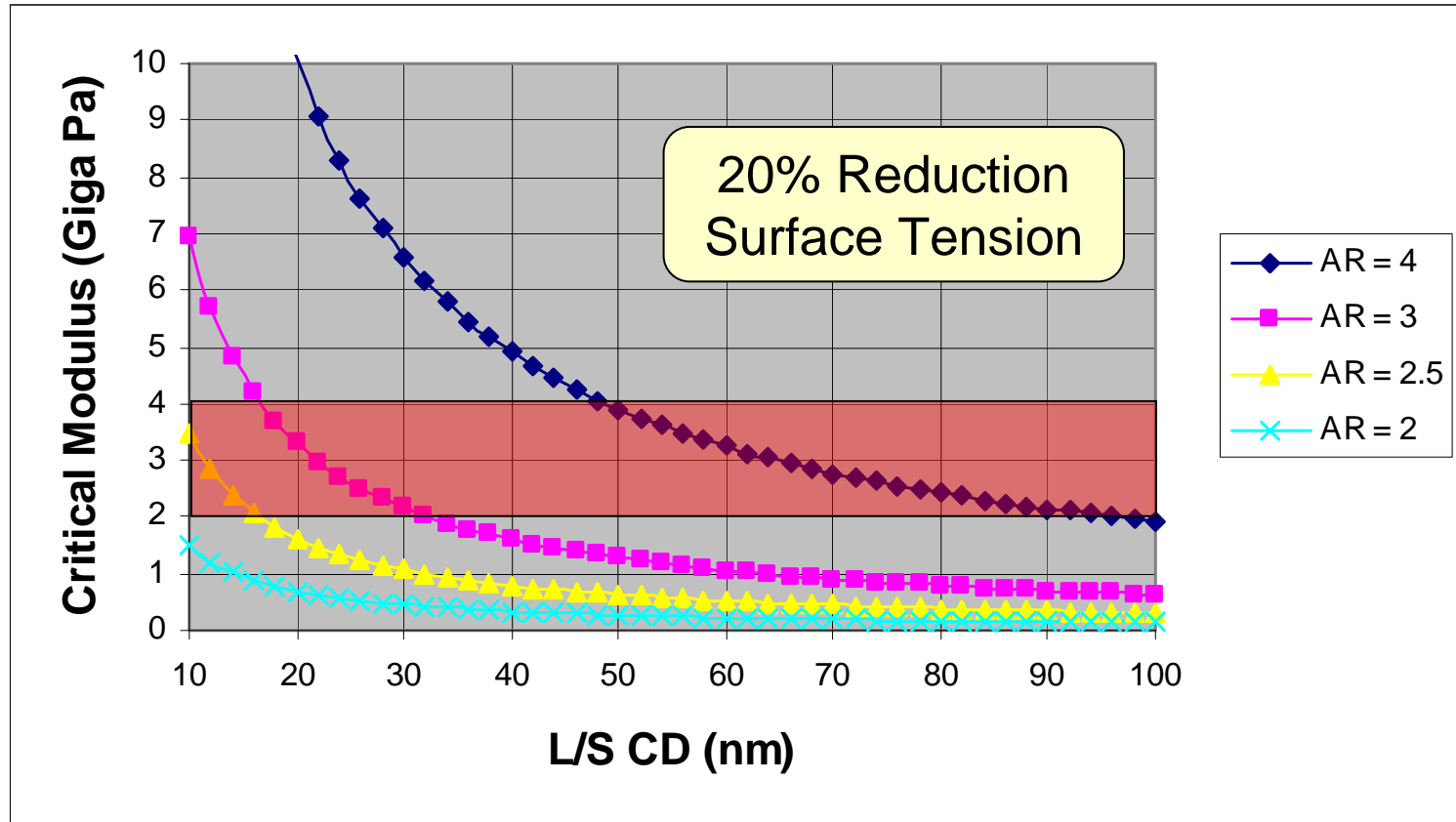
T. Tanaka, et al., Jpn J. Appl. Phys., Vol. 32 (1993) Pt. 1, No. 12B, pp. 6059

Using Surface Tension to Control Critical Modulus of Collapse



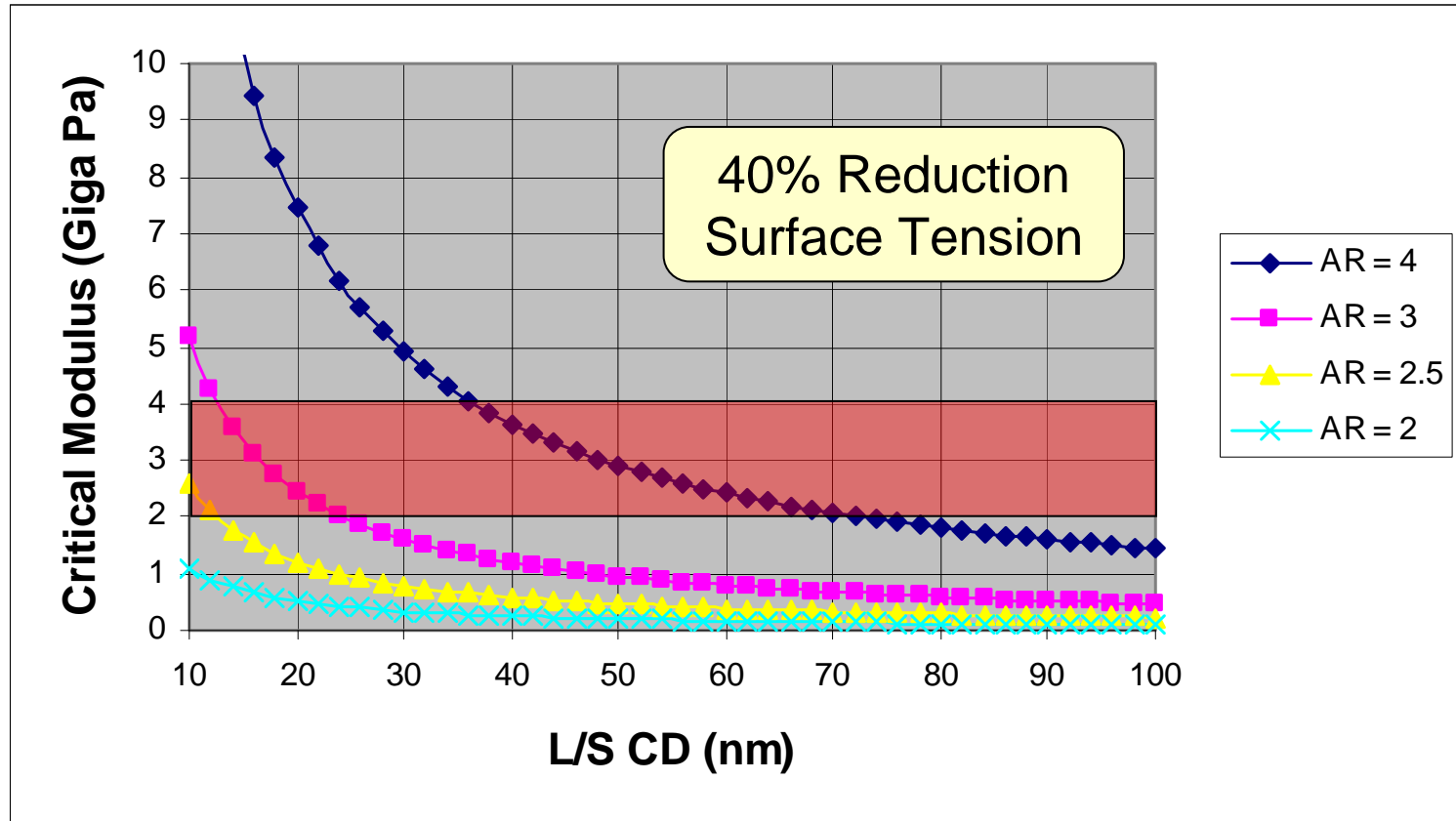
Assumptions: $\sigma = 72 \text{ mN/m}$
 $\theta = 60 \text{ degrees}$

Using Surface Tension to Control Critical Modulus of Collapse



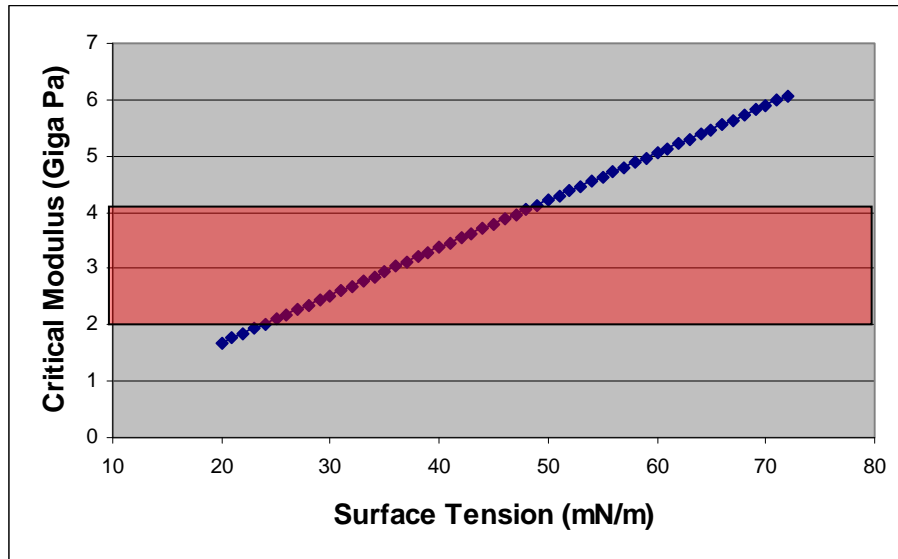
Assumptions: $\sigma = 58 \text{ mN/m}$
 $\theta = 60 \text{ degrees}$

Using Surface Tension to Control Critical Modulus of Collapse



Assumptions: $\sigma = 43 \text{ mN/m}$
 $\theta = 60 \text{ degrees}$

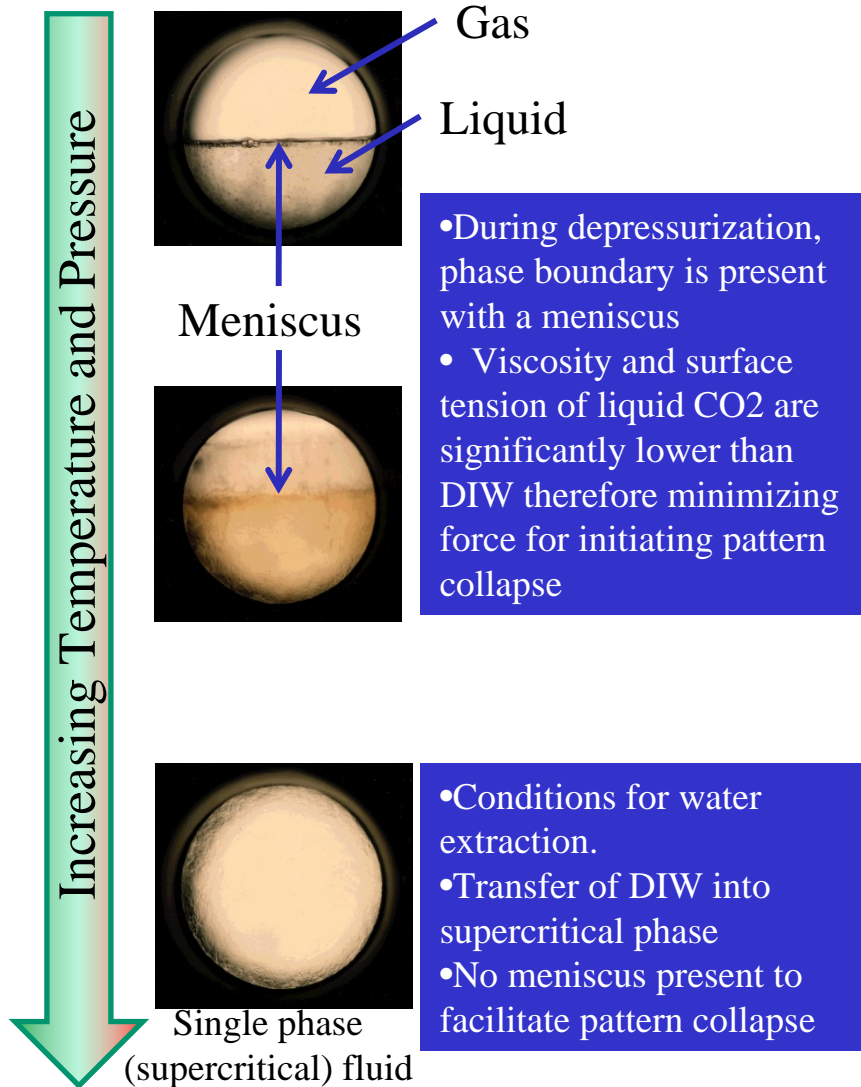
Using Surface Tension to Control Critical Modulus of Collapse



Assumptions: $H = 50$ nm
 $L = 16$ nm
 $d = 16$ nm
 $\theta = 60$ degrees

- **Surface tension allows for a linear reduction of E_C**
- **Several methods of surface tension control available**
 - Surfactant rinse
 - *TEL FIRMTM*
 - Supercritical CO₂ rinse
 - Solvent rinse
- **All methods come with trade-offs**

Supercritical CO2 For Post Develop Rinsing and Drying



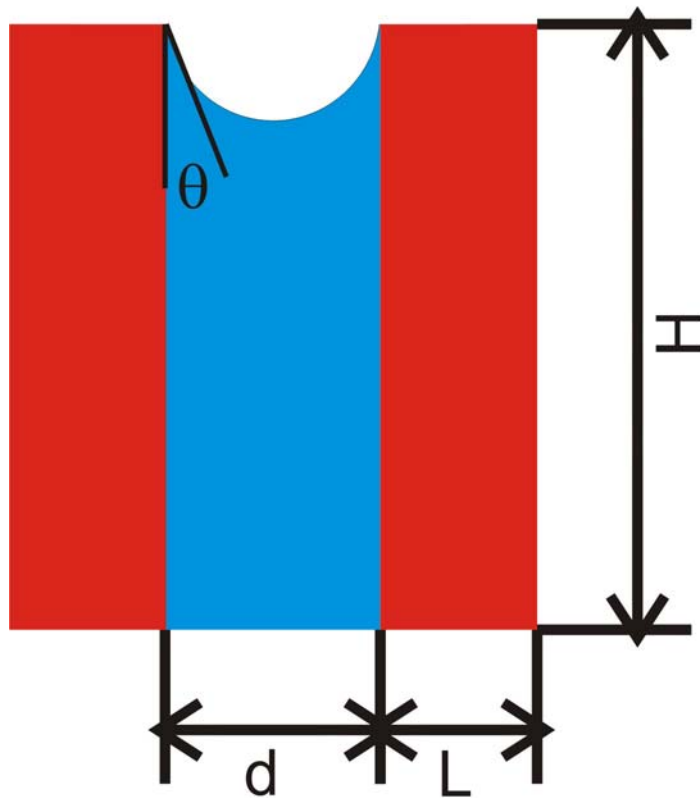
- **Advantages**

- Absence of phase boundary in supercritical phase removes mechanism for pattern collapse seen in aqueous systems
- Tunable solvent properties of scCO₂
- Phase boundary is present during depressurization but liquid CO₂ has significantly lower surface tension and viscosity

- **Disadvantages**

- Cost of high pressure processing and facility equipment
- Resist has to be designed to minimize resist swelling
- Numerous hardware and process engineering and safety challenges

Line Pattern Collapse



E_C = Critical Modulus

d = Space Width

L = Line Width

H = Line Height

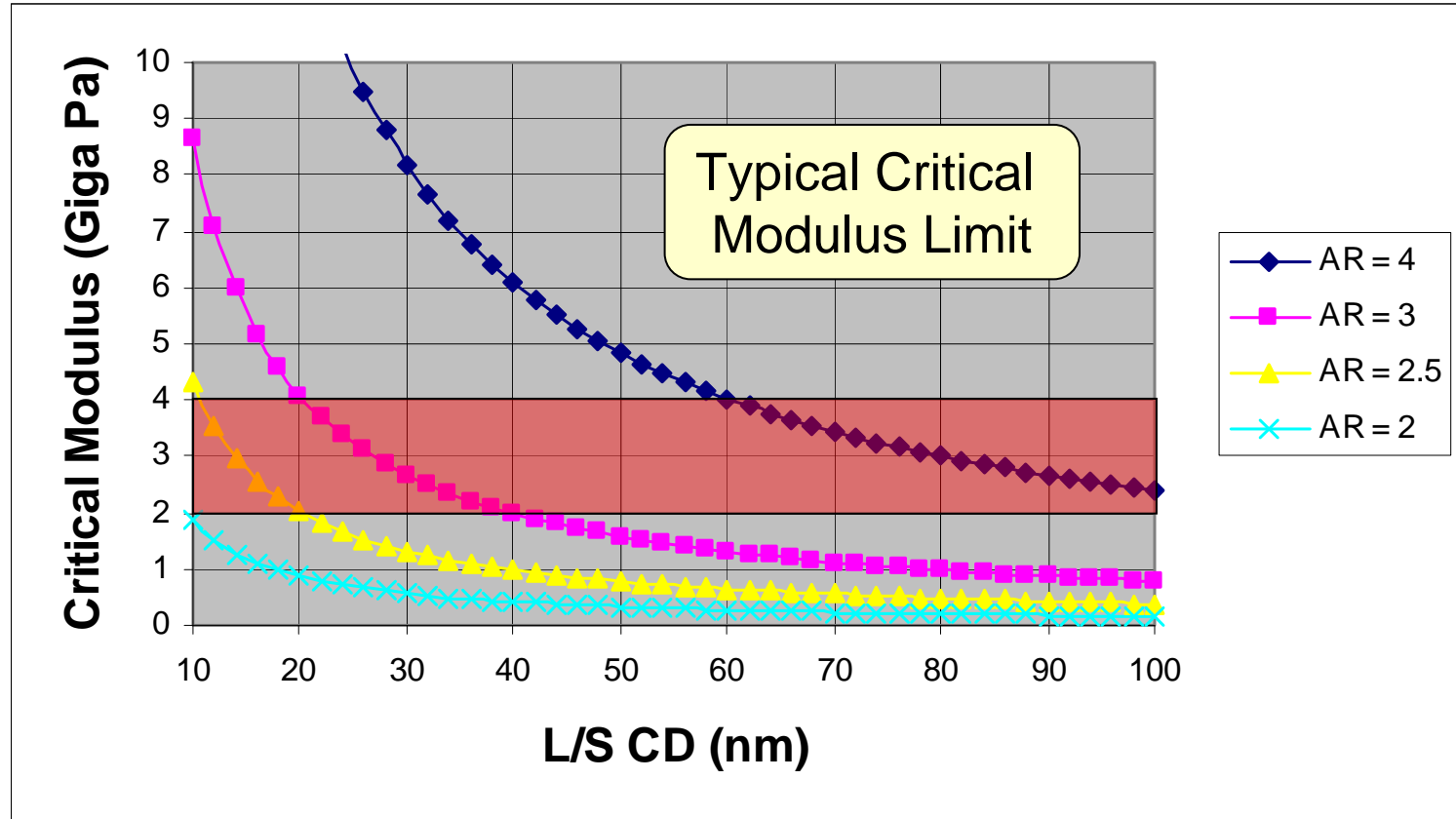
θ = Contact Angle

σ = Surface Tension

$$E_C = 4\sigma H^3 \left(\frac{3H \cos(\theta) + d \sin(\theta) + \sqrt{9H^2 \cos^2(\theta) + 6dH \sin(\theta) \cos(\theta)}}{L^3 d^2} \right)$$

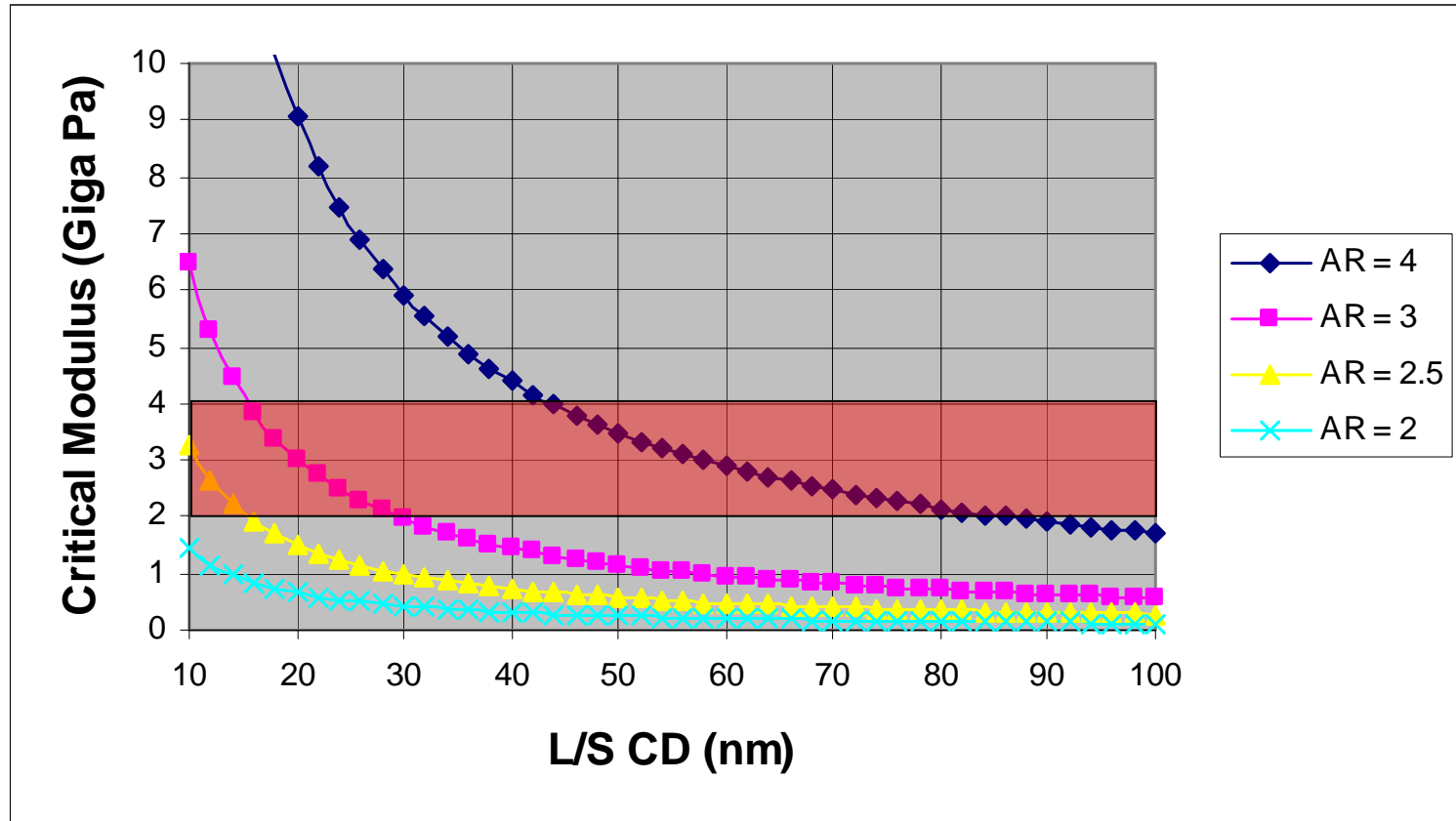
T. Tanaka, et al., Jpn J. Appl. Phys., Vol. 32 (1993) Pt. 1, No. 12B, pp. 6059

Using Contact Angle to Control Critical Modulus of Collapse



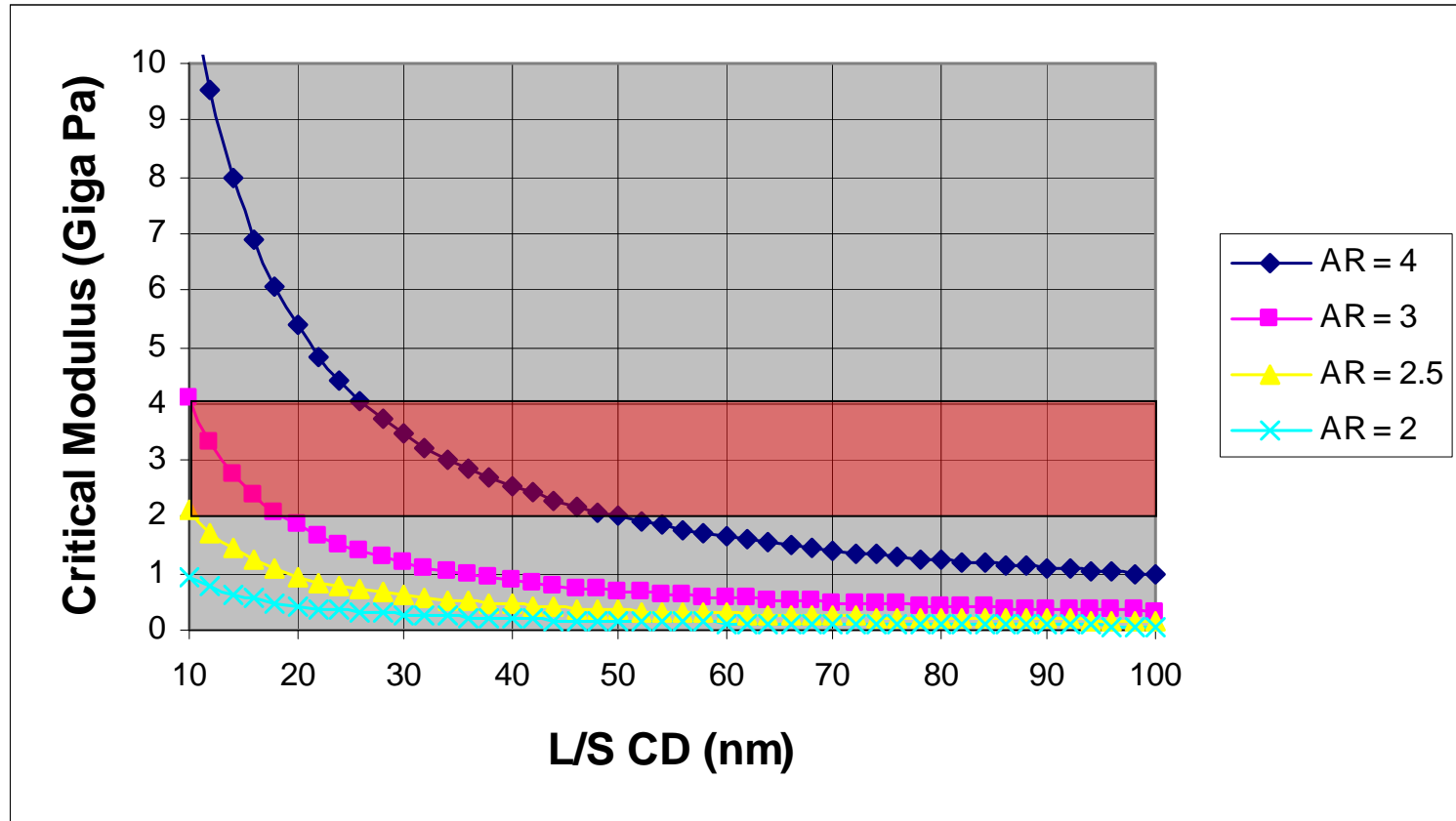
Assumptions: $\sigma = 72 \text{ mN/m}$
 $\theta = 60 \text{ degrees}$

Using Contact Angle to Control Critical Modulus of Collapse



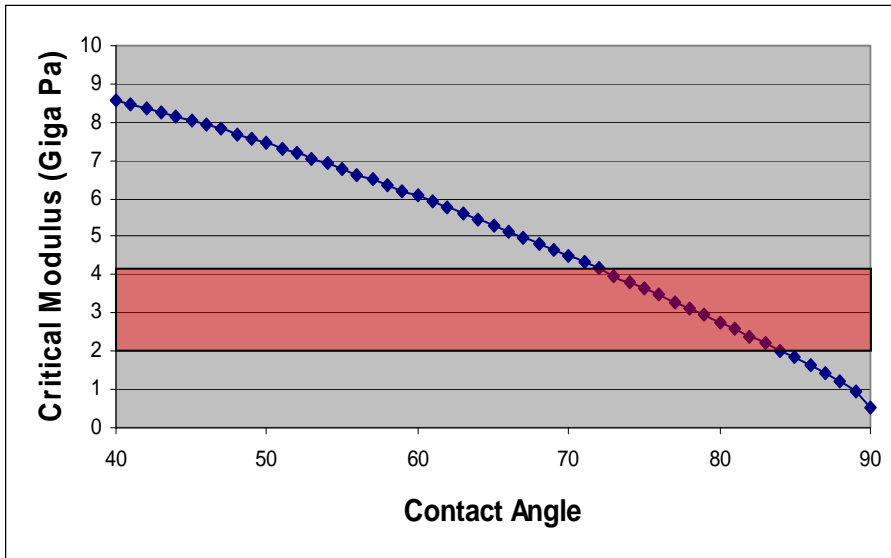
Assumptions: $\sigma = 72 \text{ mN/m}$
 $\theta = 70 \text{ degrees}$

Using Contact Angle to Control Critical Modulus of Collapse



Assumptions: $\sigma = 72 \text{ mN/m}$
 $\theta = 80 \text{ degrees}$

Using Surface Tension to Control Critical Modulus of Collapse



Assumptions: $H = 50$ nm
 $L = 16$ nm
 $d = 16$ nm
 $\sigma = 72$ mN/m

- Increasing contact angle has a non-linear impact on critical modulus
- Contact angle values in the 80 degree range are common for topcoat less immersion resists
- Might be possible with surface modification from post develop rinse

Summary

- **Line pattern collapse (LPC) has been a concern in the industry for many years**
- **LPC has been minimized by continued shrinking of resist film thickness through improved etch and bi/tri layer strategies**
- **Continued reduction in film thickness may not be possible due to confinement effects**
- **Fortunately many opportunities exist for us to address the problem**
 - Increased resist modulus
 - Decreased surface tension
 - Increased contact angle
- **TEL is working to evaluate these options and provide the solutions our customers need to address this issue**