Challenges Associated with Line Pattern Collapse for EUV Lithography

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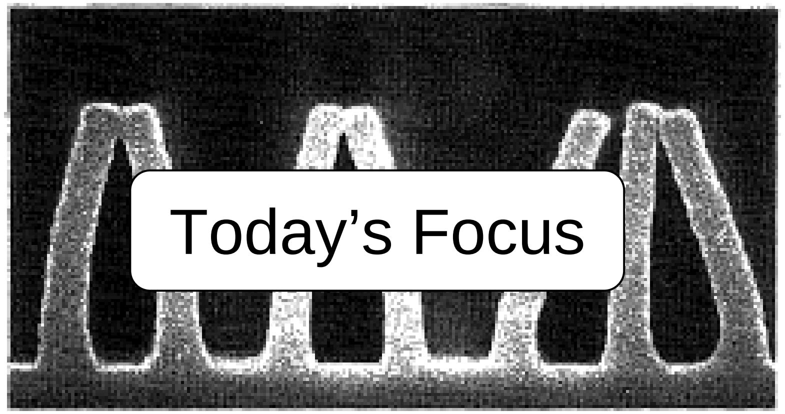
TOKYO ELECTRON

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**

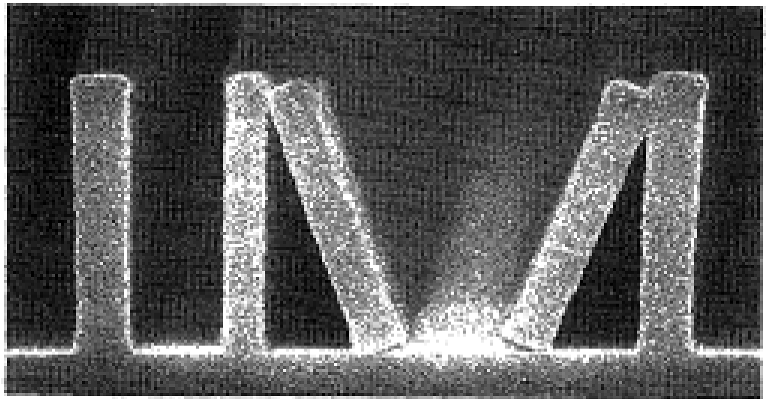
Line Pattern Collapse

Bending Failure



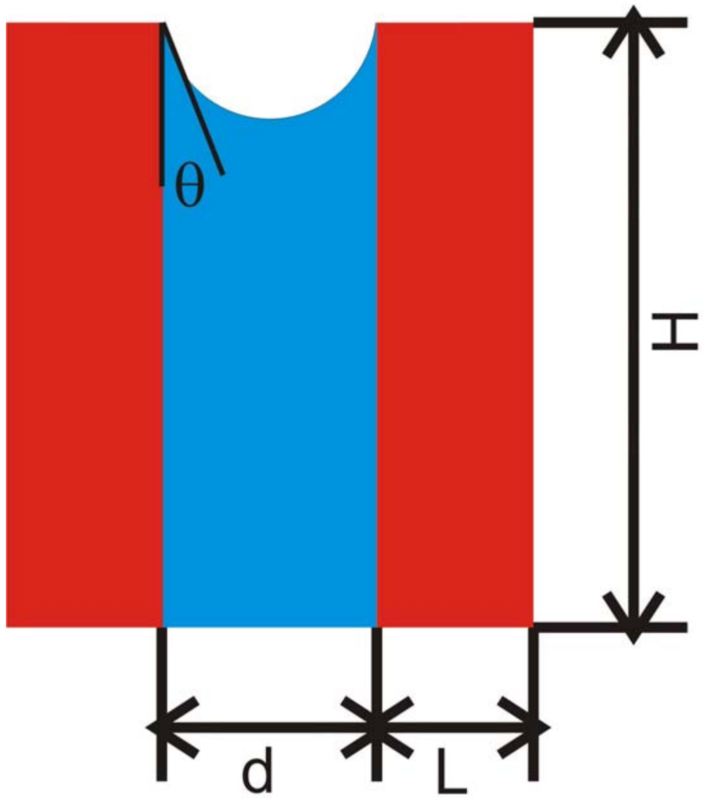
Capillary force exceeds the critical modulus of resist material.

Adhesion Failure



Capillary force exceeds the adhesive force between resist and substrate

Line Pattern Collapse – The Critical Parameters

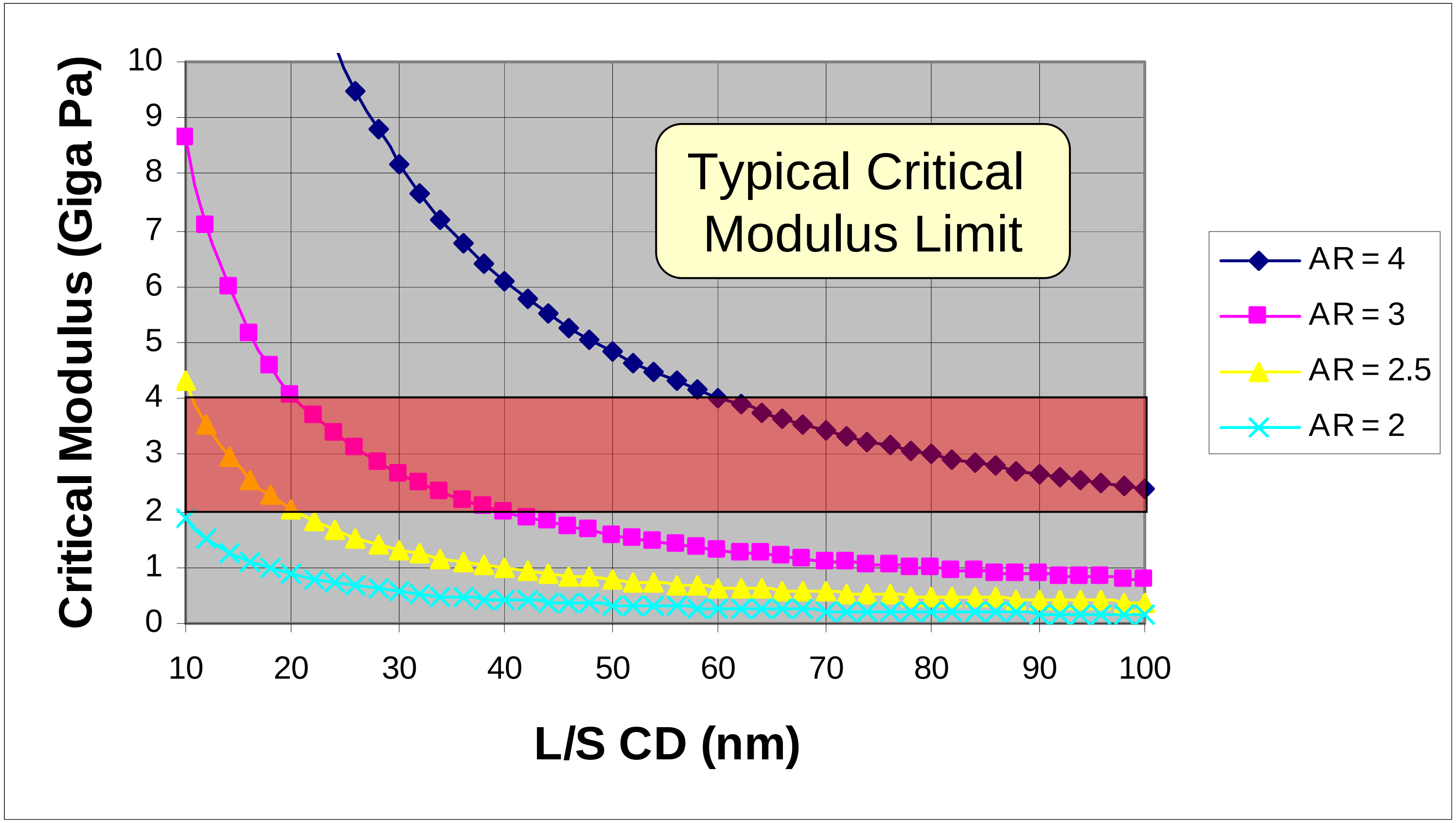


E_C = Critical Modulus
d = Space Width
L = Line Width
H = Line Height
θ = Contact Angle
σ = Surface Tension

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

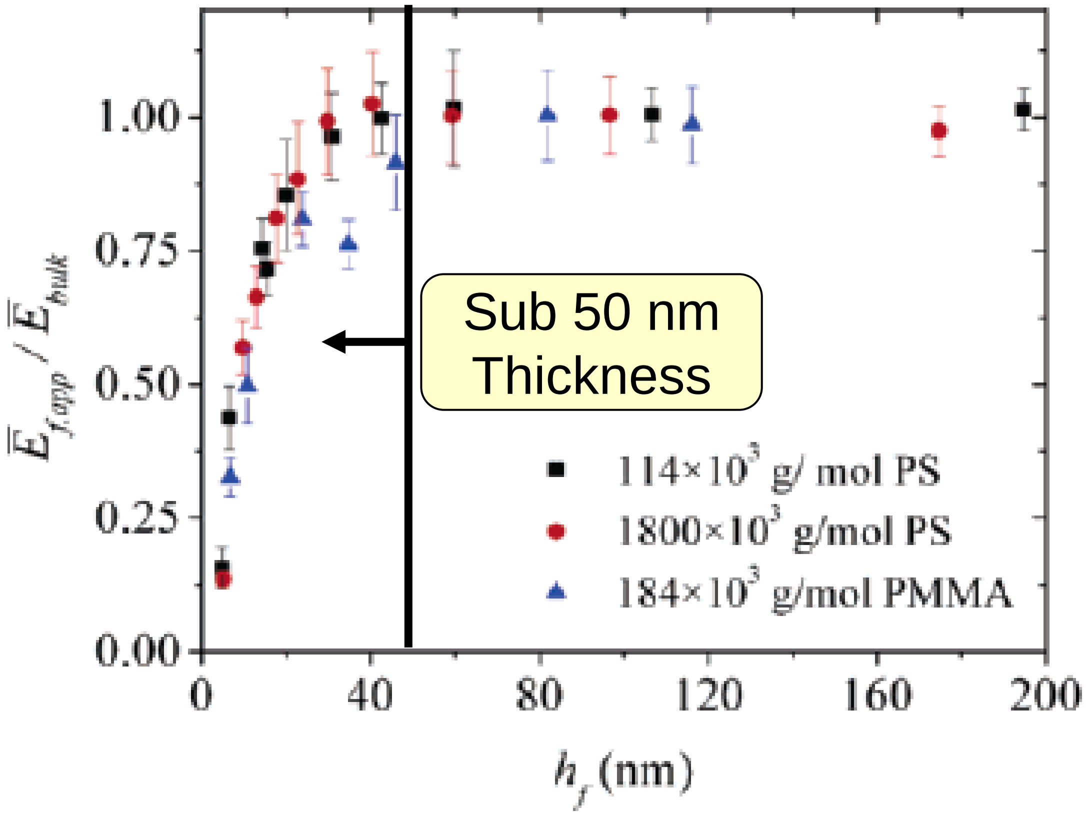
T. Tanaka, et al., Jpn J. Appl. Phys., Vol. 32 (1993) Pt. 1, No. 12B, pp. 6059

Critical Modulus of Collapse



Assumptions: σ = 72 mN/m
θ = 60 degrees

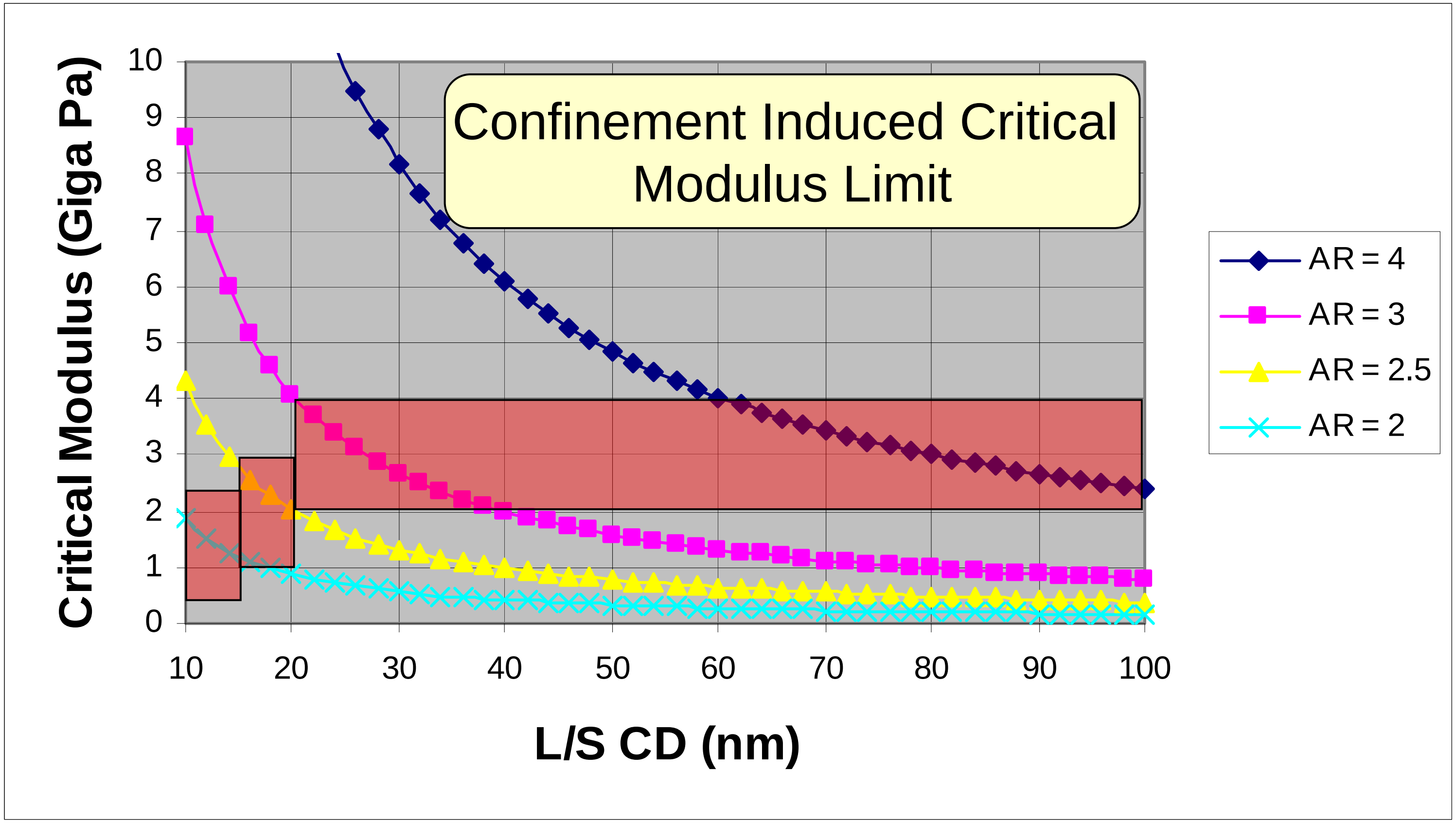
Thin Film Confinement Effects



Below 50 nm thickness modulus can reduce quickly

Stafford, et. Al., Marcromolecules, 2006, 39, 5095-5099

Confinement Induced Critical Modulus of Collapse



Assumptions: σ = 72 mN/m
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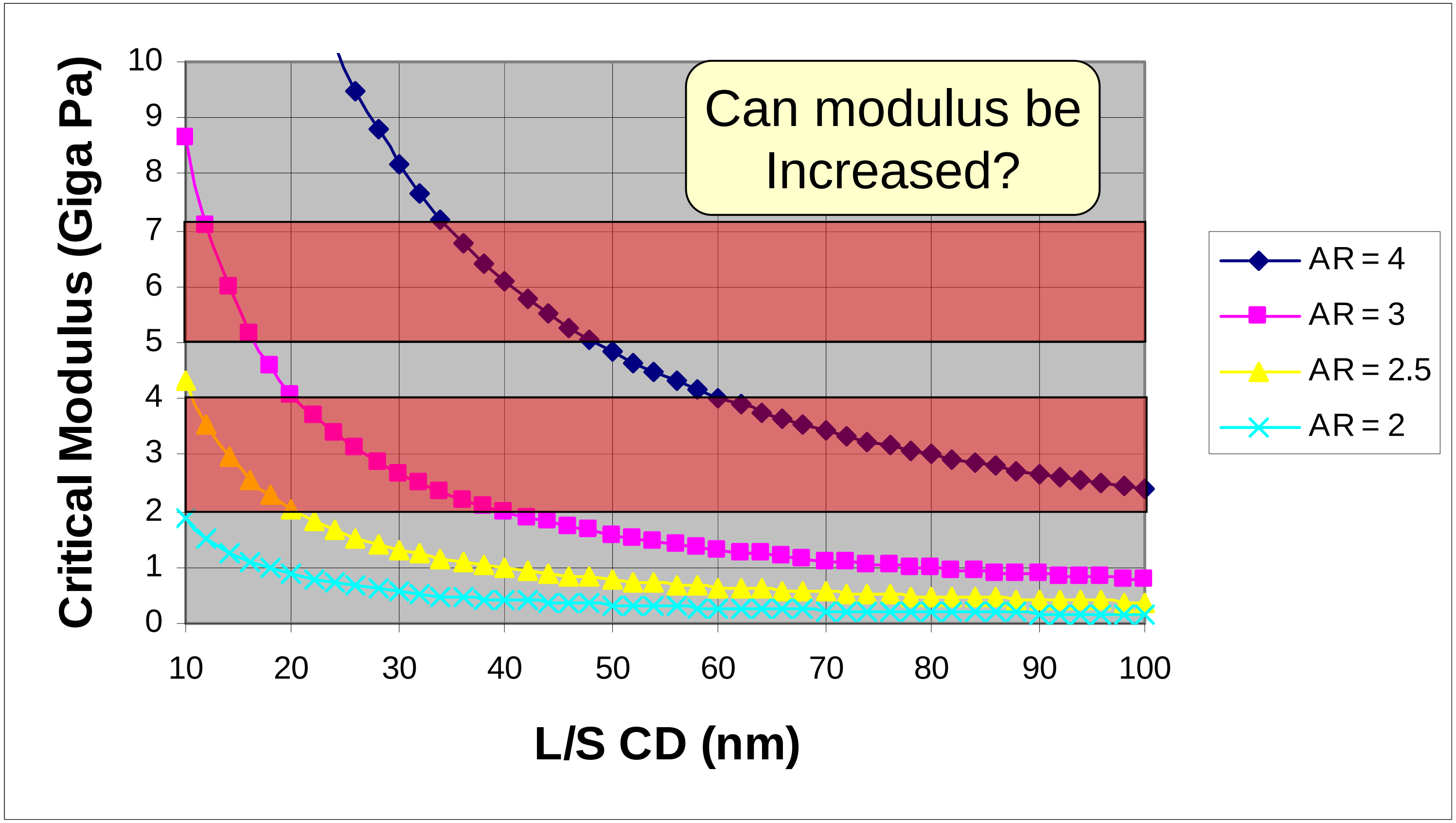
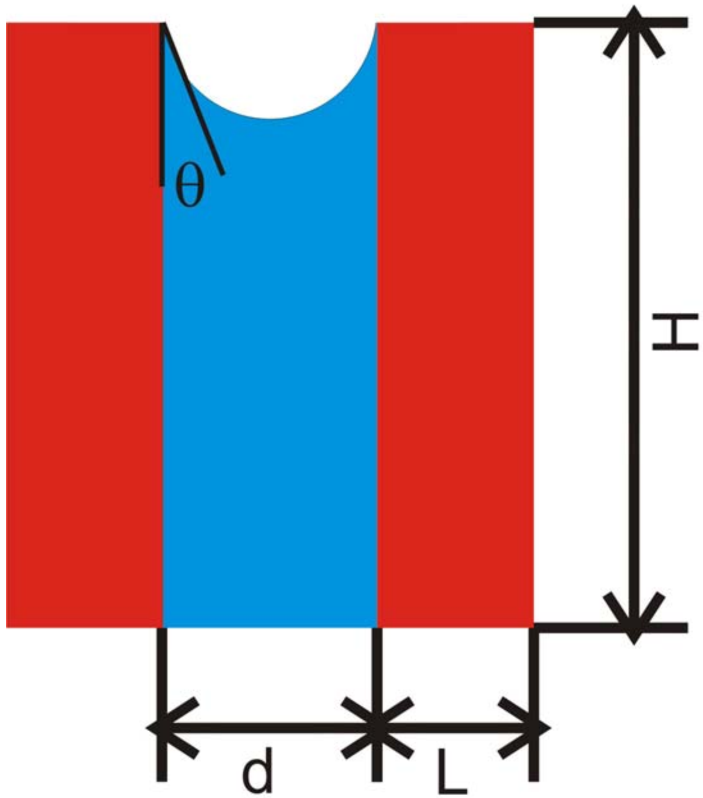
** Confinement Induced Critical Modulus Limit for Visualization only, it is not rigorously calculated

Increasing Critical Modulus of Collapse



Assumptions: σ = 72 mN/m
θ = 60 degrees

Line Pattern Collapse



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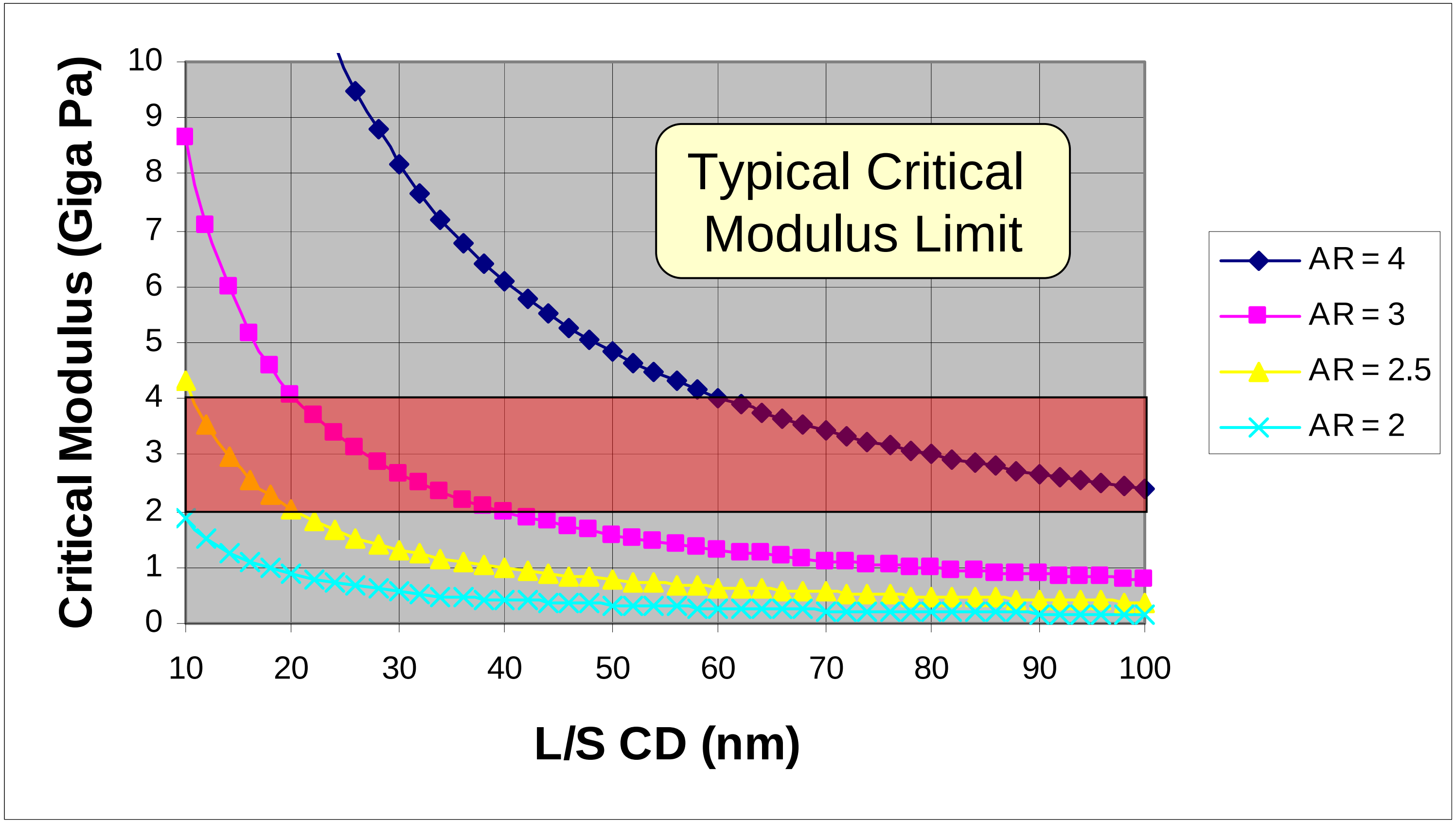
Using Surface Tension to Control Critical Modulus of Collapse



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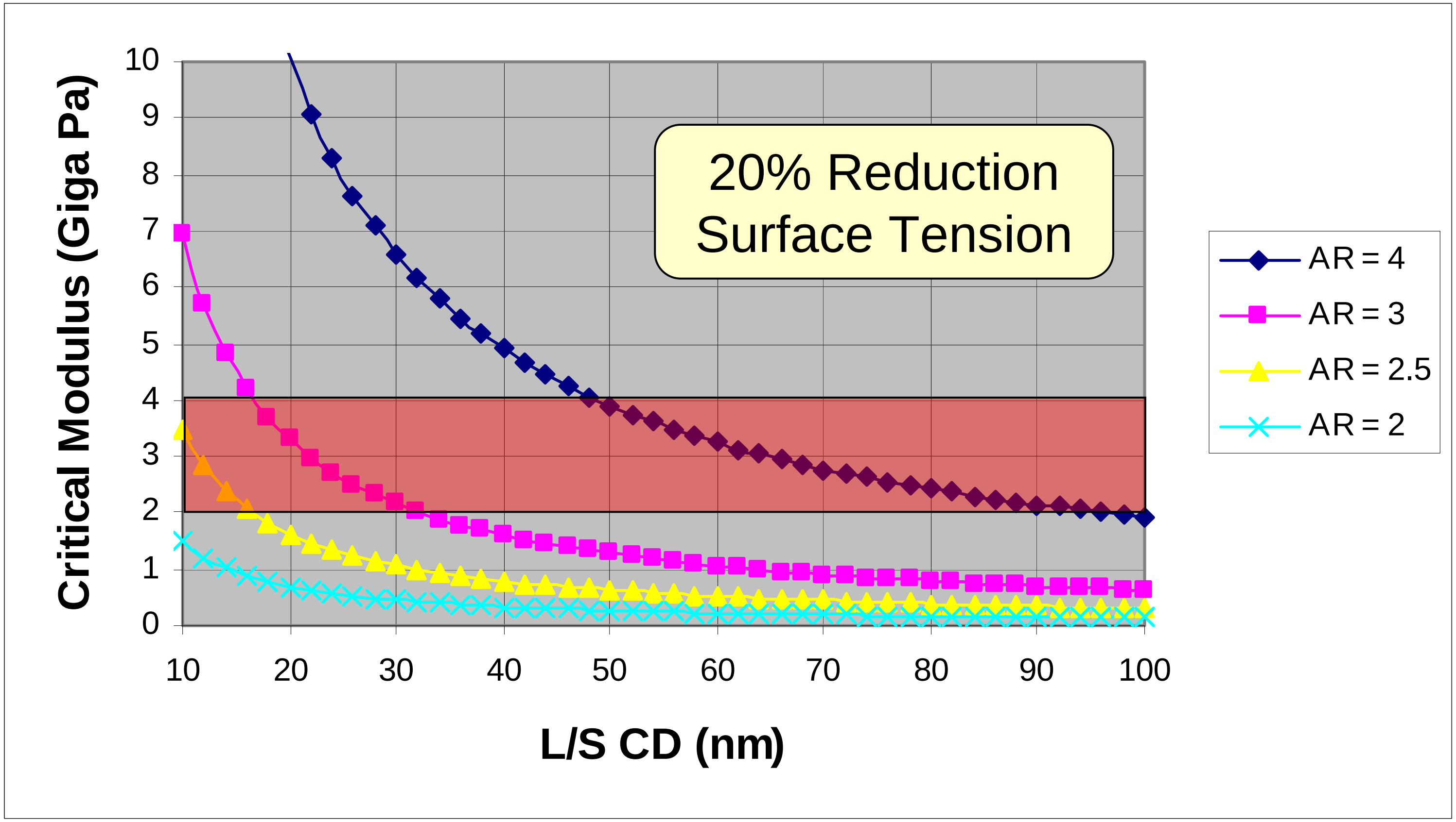
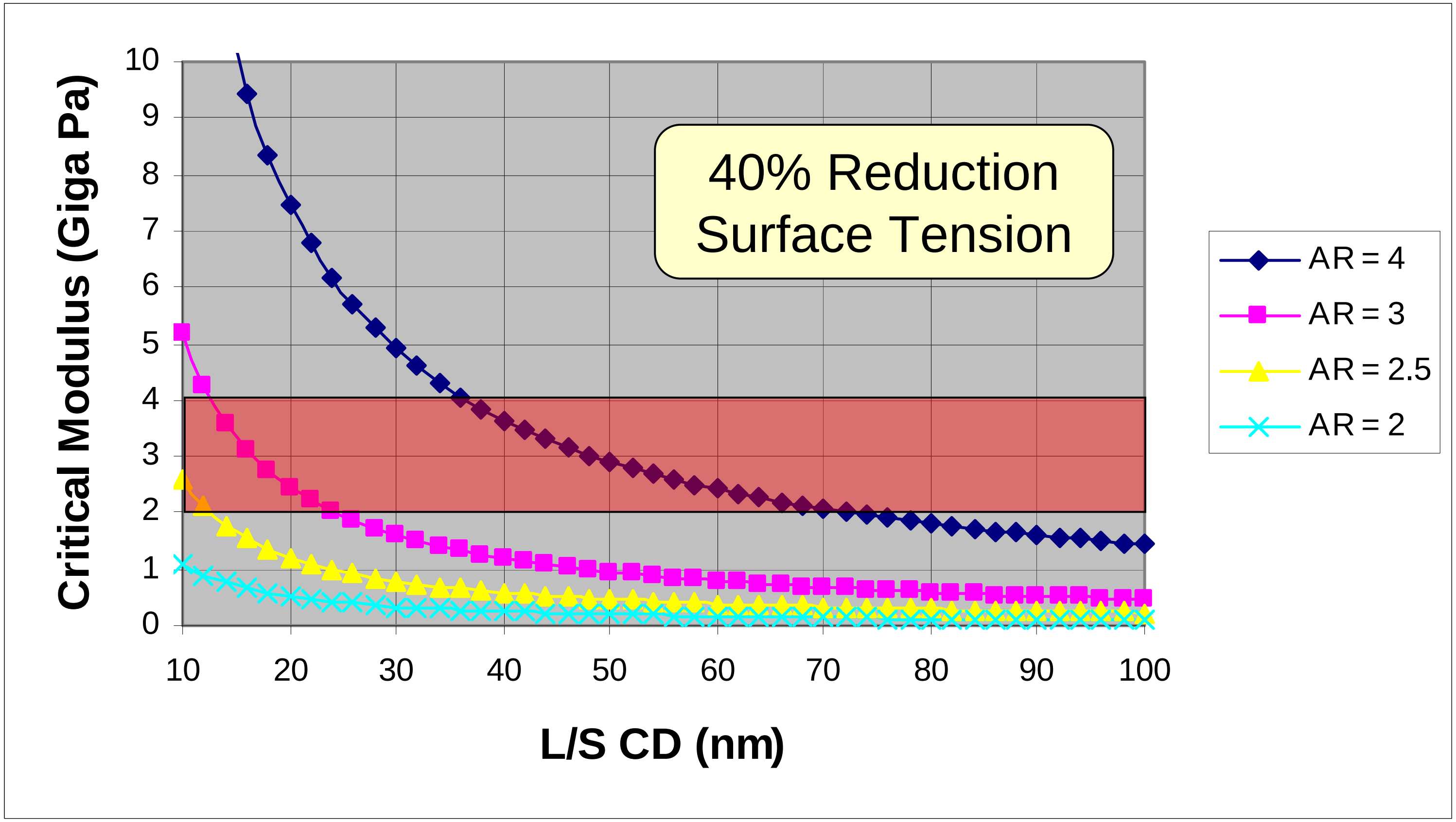
Using Surface Tension to Control Critical Modulus of Collapse



Assumptions: σ = 58 mN/m
θ = 60 degrees

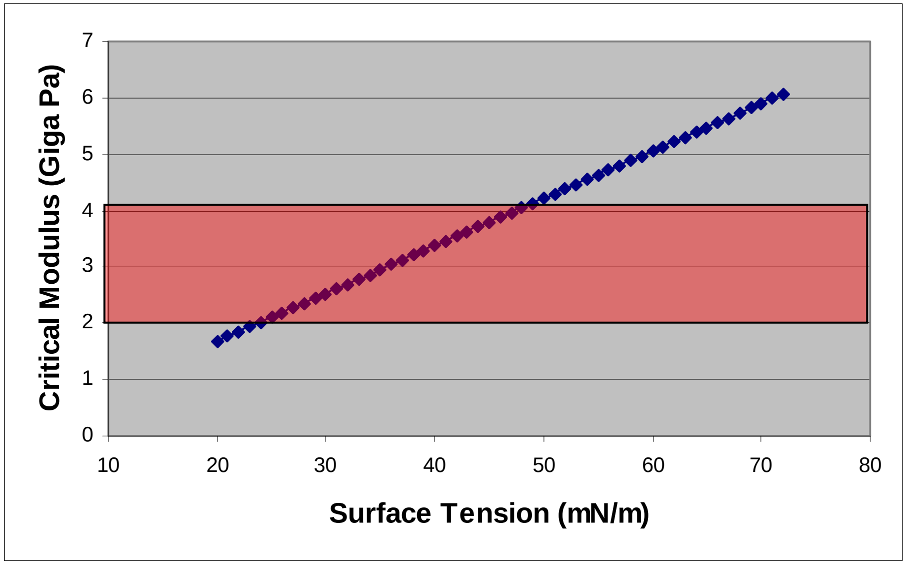
Using Surface Tension to Control Critical Modulus of Collapse



Assumptions: σ = 43 mN/m

θ = 60 degrees

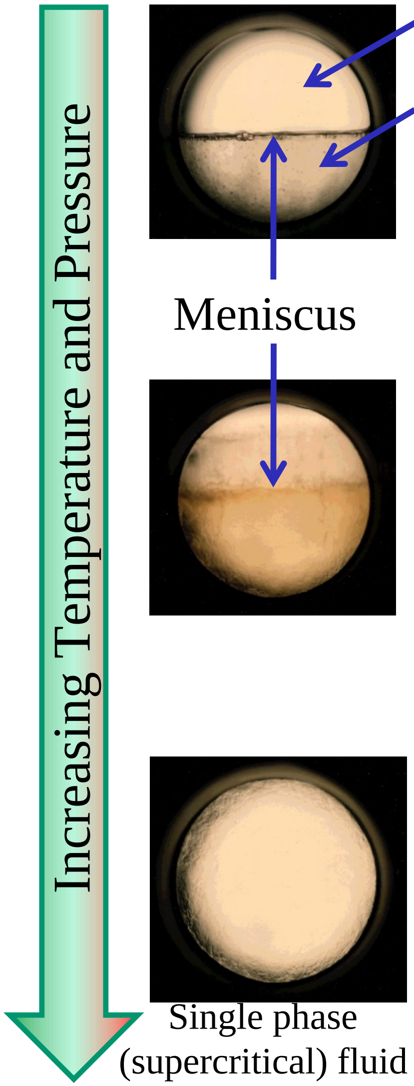
Using Surface Tension to Control Critical Modulus of Collapse



Assumptions:
H= 50 nm
L = 16 nm
d = 16 nm
θ = 60 degrees

- **Surface tension allows for a linear reduction of E_C**
- **Several methods of surface tension control available**
  - Surfactant rinse
    - *TEL FIRM™*
  - Supercritical CO_2 rinse
  - Solvent rinse
- **All methods come with trade-offs**

Supercritical CO2 For Post Develop Rinsing and Drying

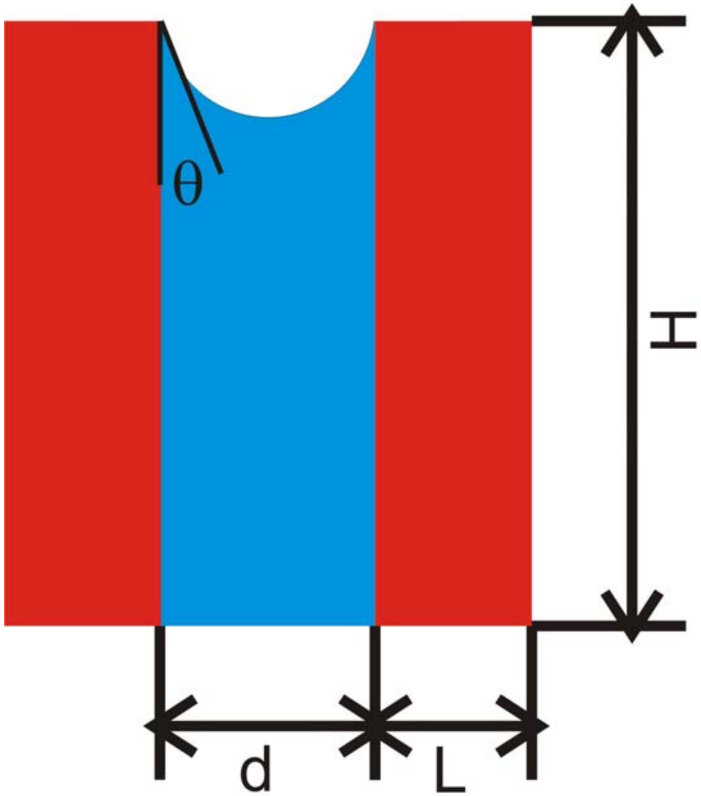


- During depressurization, phase boundary is present with a meniscus
- Viscosity and surface tension of liquid CO2 are significantly lower than DIW therefore minimizing force for initiating pattern collapse

- Conditions for water extraction.
- Transfer of DIW into supercritical phase
- No meniscus present to facilitate pattern collapse

- **Advantages**
  - Absence of phase boundary in supercritical phase removes mechanism for pattern collapse seen in aqueous systems
  - Tunable solvent properties of scCO_2
  - Phase boundary is present during depressurization but liquid CO_2 has significantly lower surface tension and viscosity
- **Disadvangates**
  - 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



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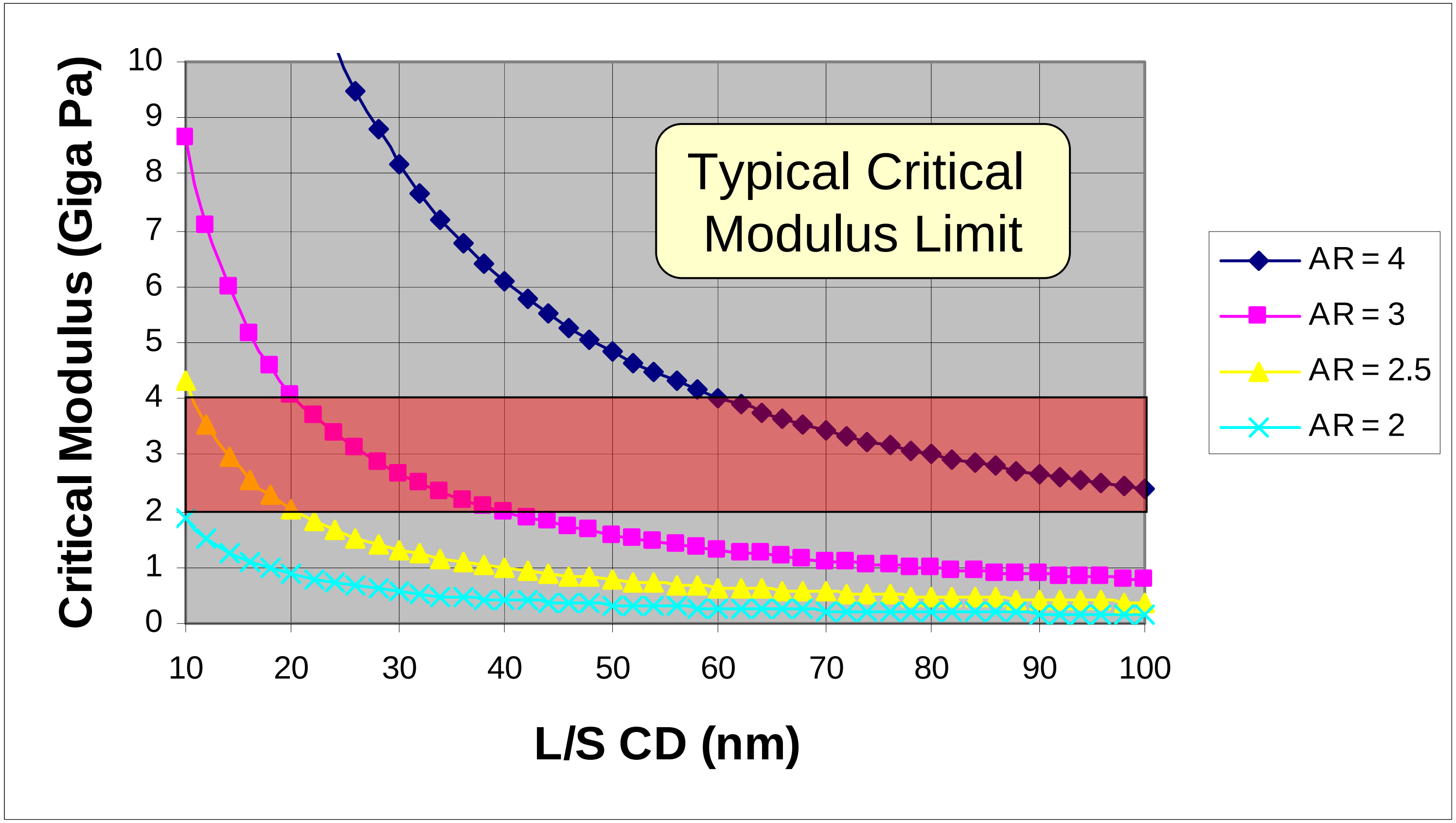
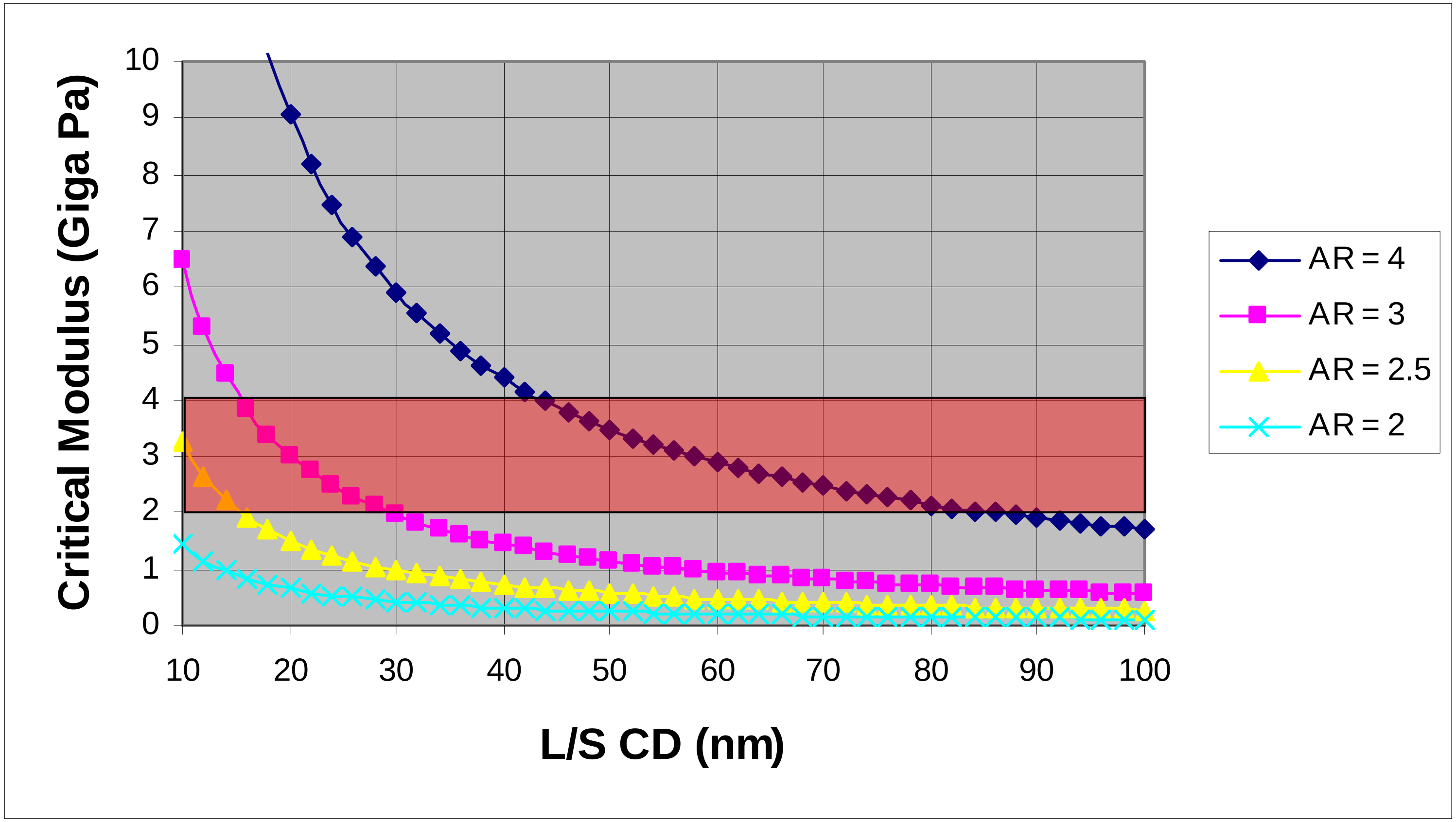
T. Tanaka, et al., Jpn J. Appl. Phys., Vol. 32 (1993) Pt. 1, No. 12B, pp. 6059

Using Contact Angle to Control Critical Modulus of Collapse



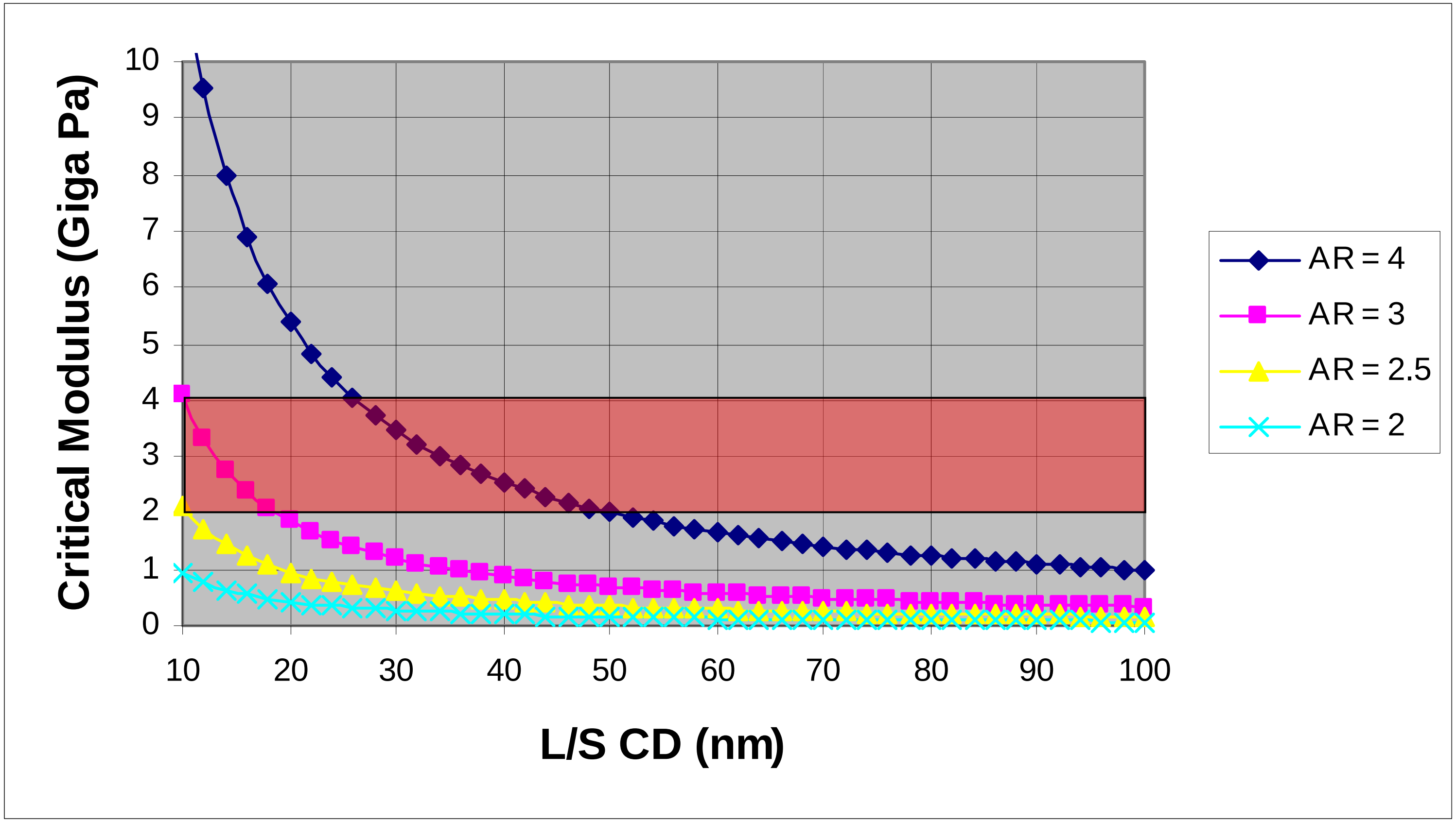
Assumptions: σ = 72 mN/m
θ = 60 degrees

Using Contact Angle to Control Critical Modulus of Collapse



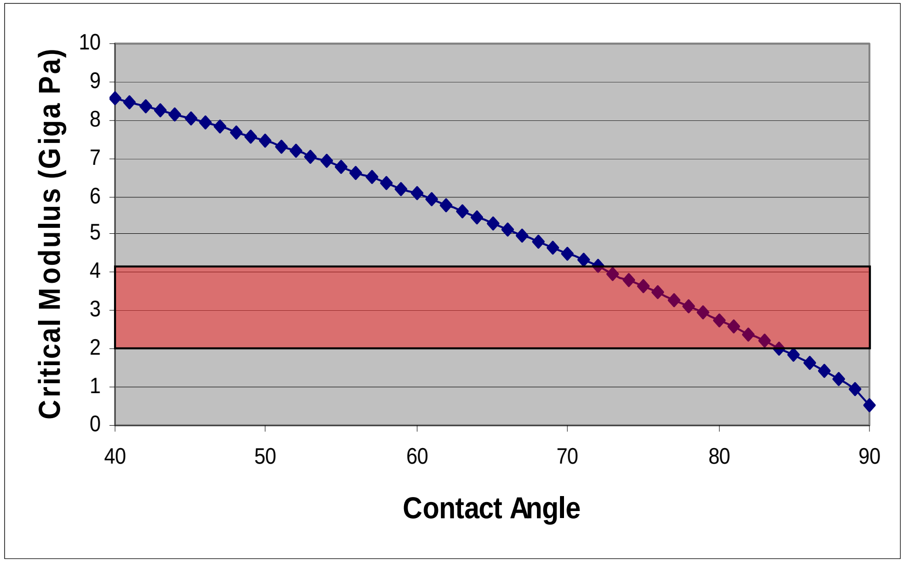
Assumptions: σ = 72 mN/m
θ = 70 degrees

Using Contact Angle to Control Critical Modulus of Collapse



Assumptions: σ = 72 mN/m
θ = 80 degrees

Using Surface Tension to Control Critical Modulus of Collapse



Assumptions:
H= 50 nm
L = 16 nm
d = 16 nm
σ = 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**