How & why does pattern collapse occur?

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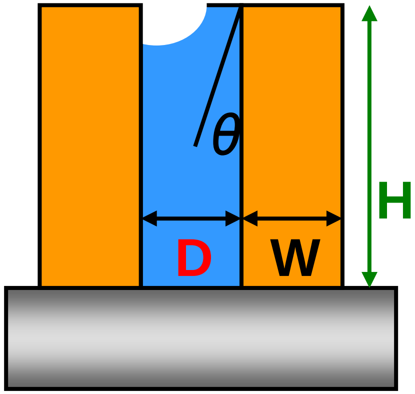
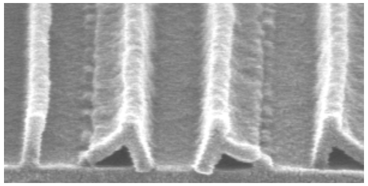
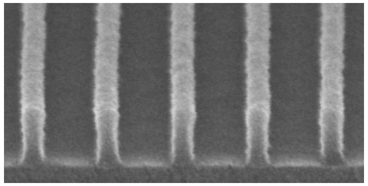
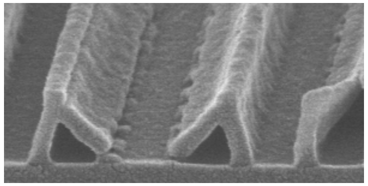
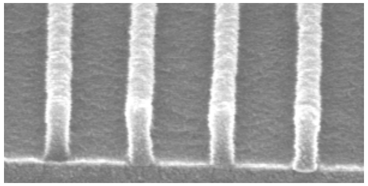
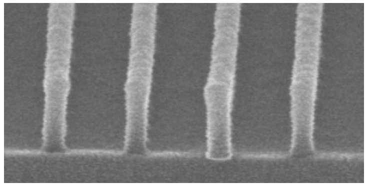
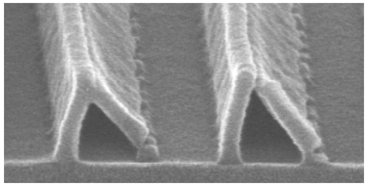
Pitch vs. Collapse Limitation

$$\sigma_{max}=6\gamma A^{2}/D\cdot\cos\theta$$

H. Namatsu et al., Appl. Phys. Lett. 66 (1995)



Line & Space (1:2)

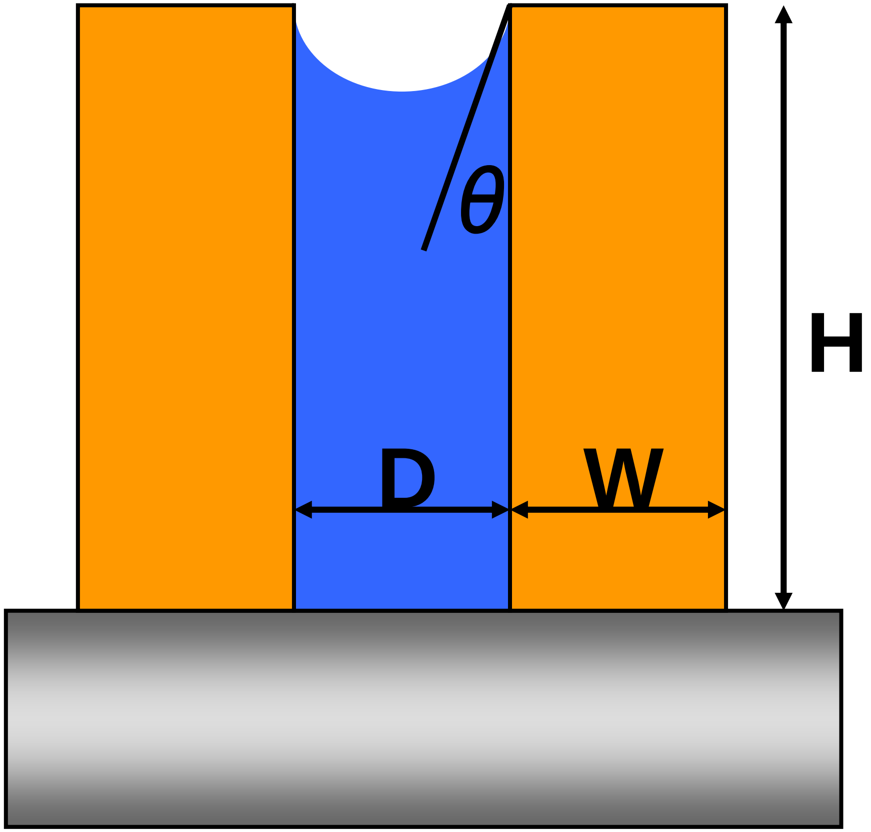
Film Thickness	**150nmT**	**200nmT**	**250nmT**
Aspect Ratio	**AR= 2.81**	**AR= 3.33**	**AR= 3.75**
160nm Pitch			
180nm Pitch			
200nm Pitch			

The tightening pitch do not allow to keep critical aspect ratio from theoretical equation and actual evaluation result

Capillary Force

$$\sigma_{max} = 6\gamma A^2 / D \cdot \cos\theta$$

σ_{max} :Max. stress to resist
γ :Surface tension
A :Aspect ratio H/W
D :Space width
θ :Contact angle



Approaches to reduce σ_{max}

- γ → Decrease
- A → Decrease →*Undesirable*
- D → Increase →*Not an option*
- θ → 90°

Reduction of Capillary Force

γ (surface tension) reduction

Rinse with surfactant

M. Sugiyama et al., Proc. of SPIE 6519 (2007)

SCCO$_2$

M. Wagner et al., Proc. of SPIE 6153 (2006)
M. Y. Lee et al., j. of Supercritical Fluids 42 (2007) 150

θ (contact angle) → 90°

Rinse with surfactant

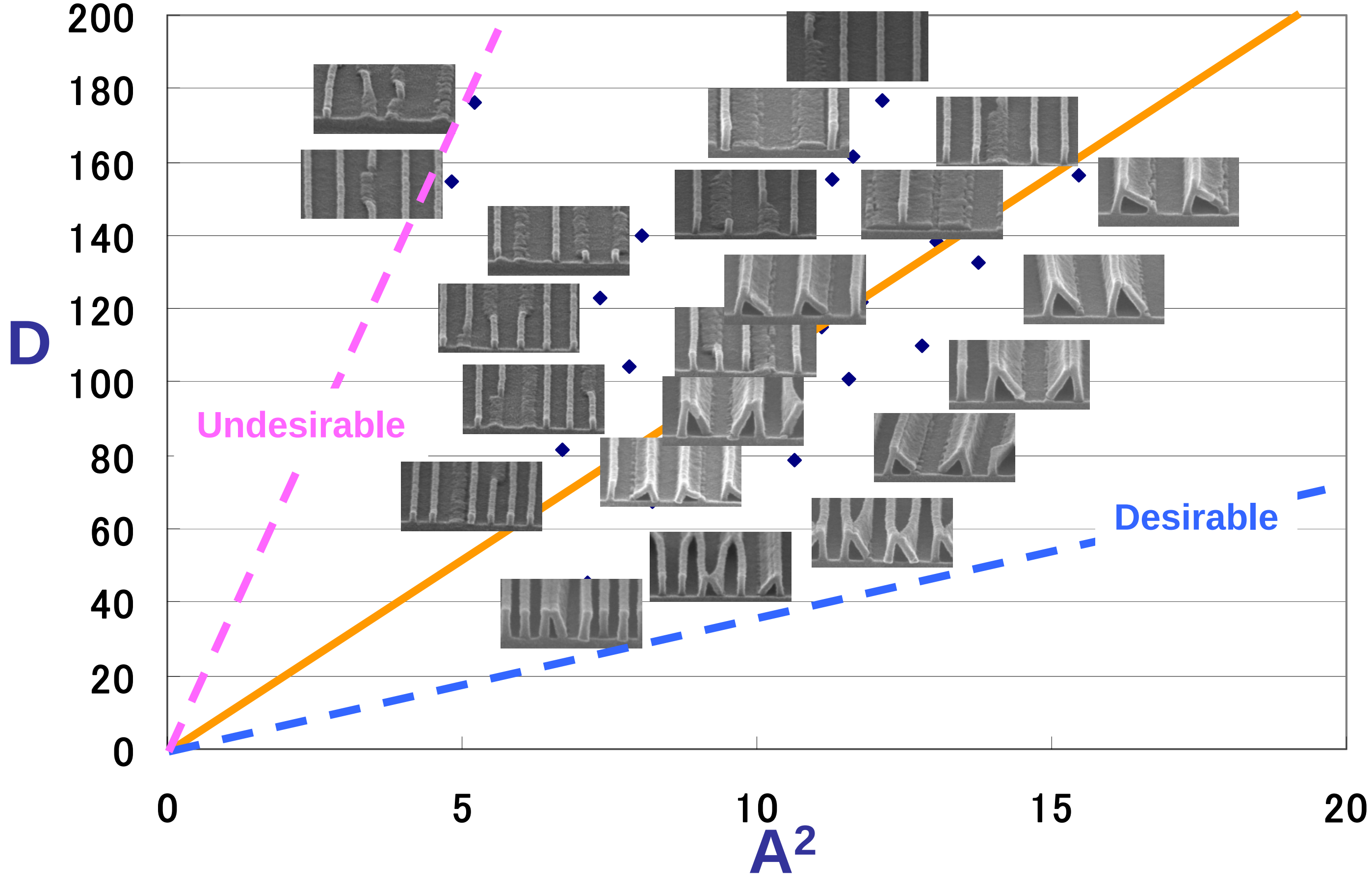
O. Miyahara et al., Proc. of SPIE 5376 (2007)
A. Drechsler et al., Colloids and surface, A: physicochem. Eng. Aspects 311(2007) 83
S. Hien et al., Proc. of SPIE 4690 (2002)

Hydrophilic surface on resist wall

S. Hien et al., Proc. of SPIE 4690 (2002)

D vs A² Plots

$$\sigma_{max}=6\gamma A^2/D\cdot\cos\theta \rightarrow D=6\gamma/\sigma_{max}\cdot\cos\theta\cdot A^2$$



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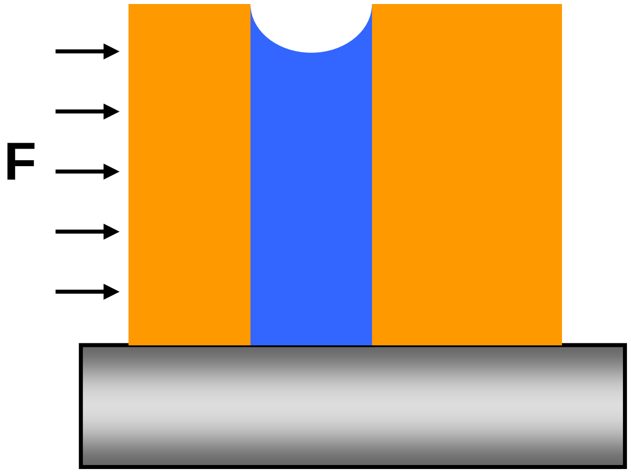
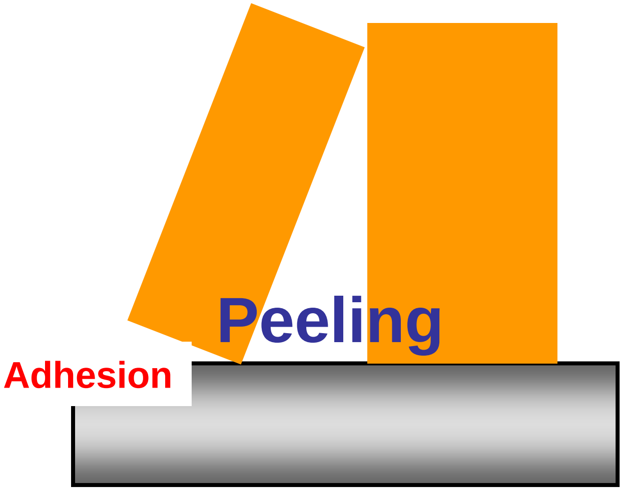
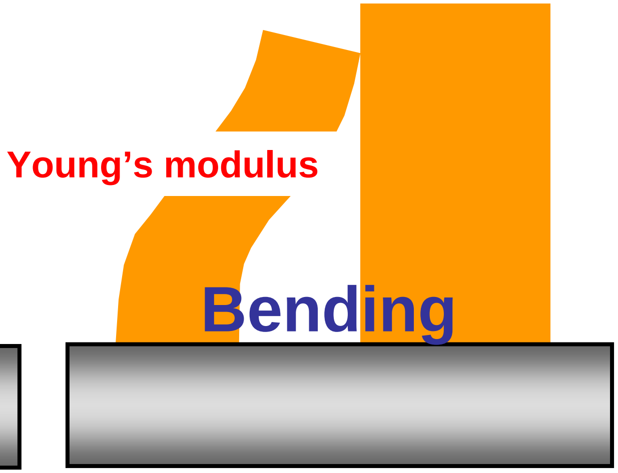
Various Collapse Mode

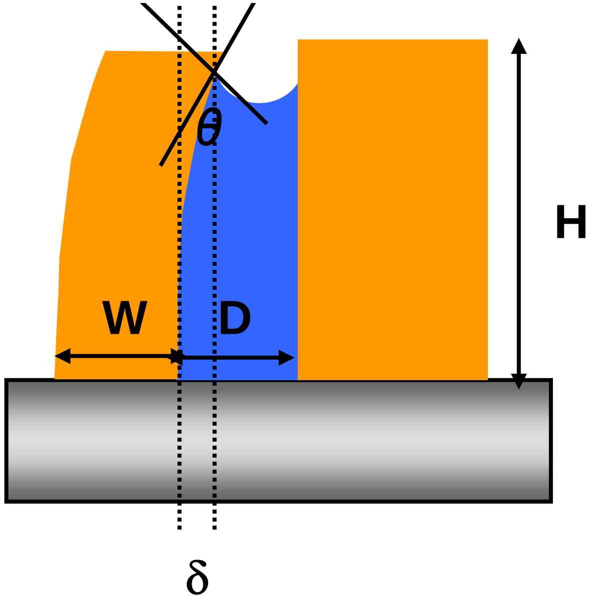






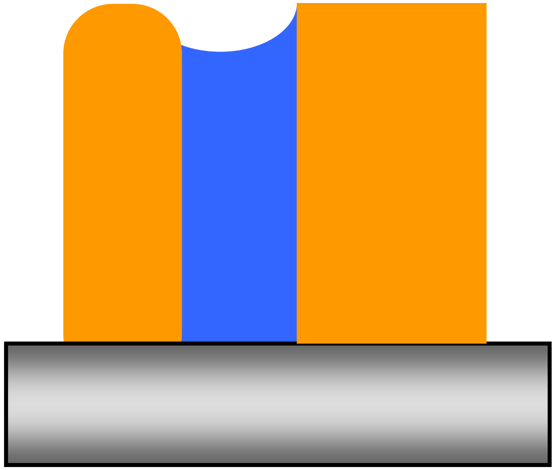
Various Collapse Model

- **Elastic deformation model 1,2)**



- **Air tunnel model 3)**

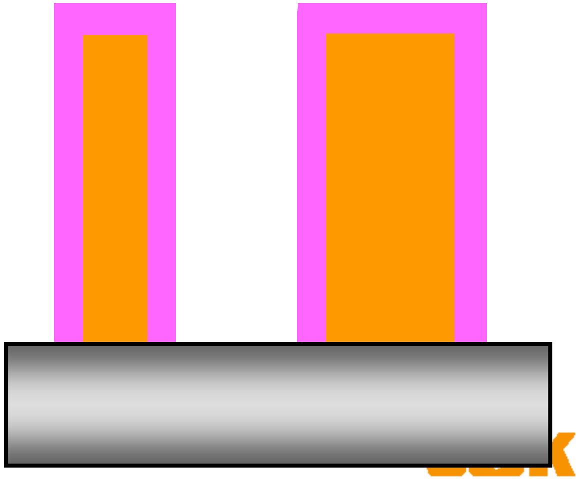
- **Shape dependence model 4)**



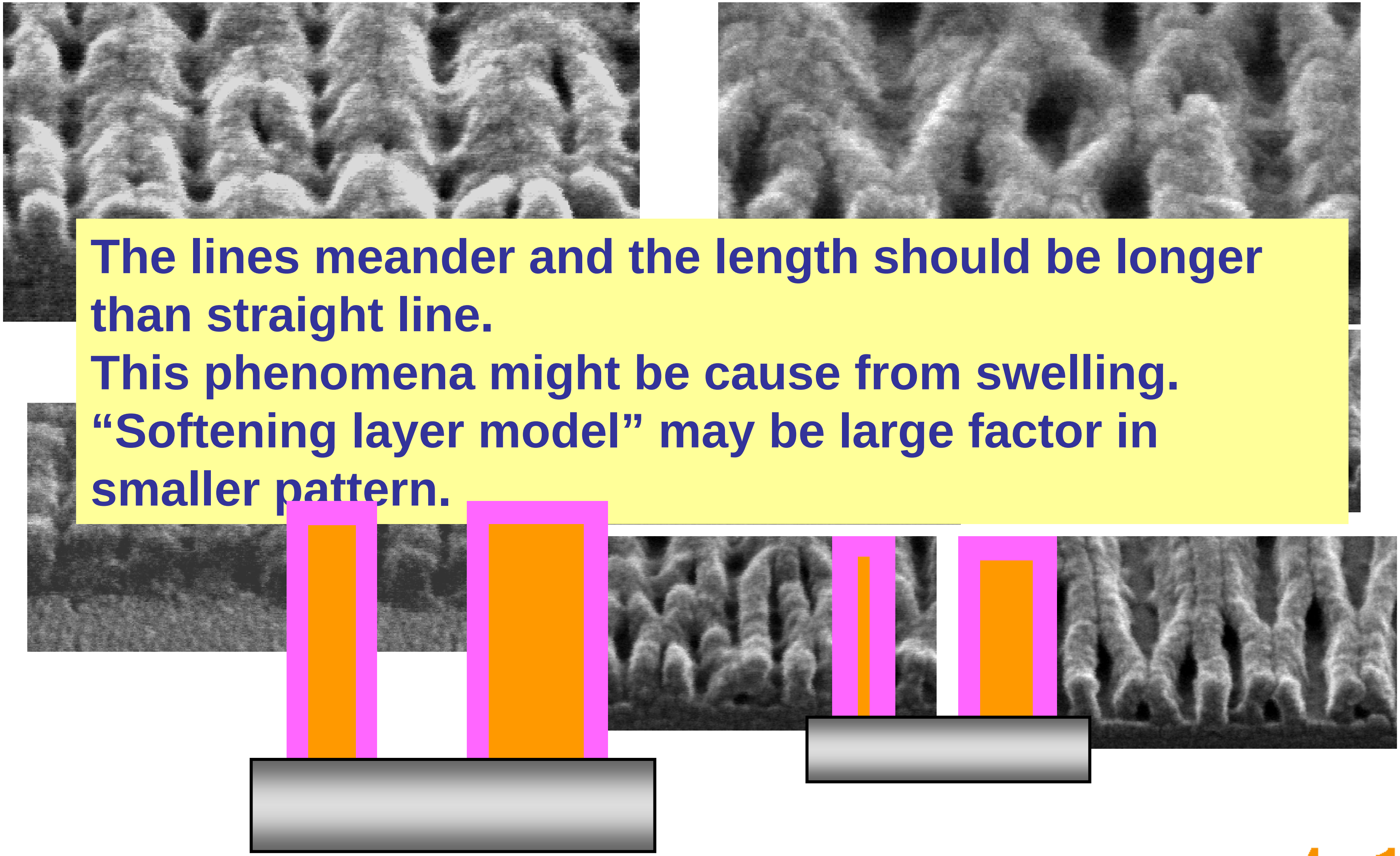
- **Adhesive model 1,2)**
- **….**

1) *A. Jouve et al., Proc. of SPIE 5753 (2005)*
2) *A. Jouve et al., Proc. of SPIE 6153 (2006)*
3) *A. Kawai et al. Jpn.J.Appll. Phys., Vol45 (2006)*
4) *A. Jouve et al. J. Vac. Technol. B 25 (2007)*
5) *A. Kawai et al., Proc. of SPIE 5753 (2005)*

- **Softening layer model 1,5)**



Collapse in EUV patterning



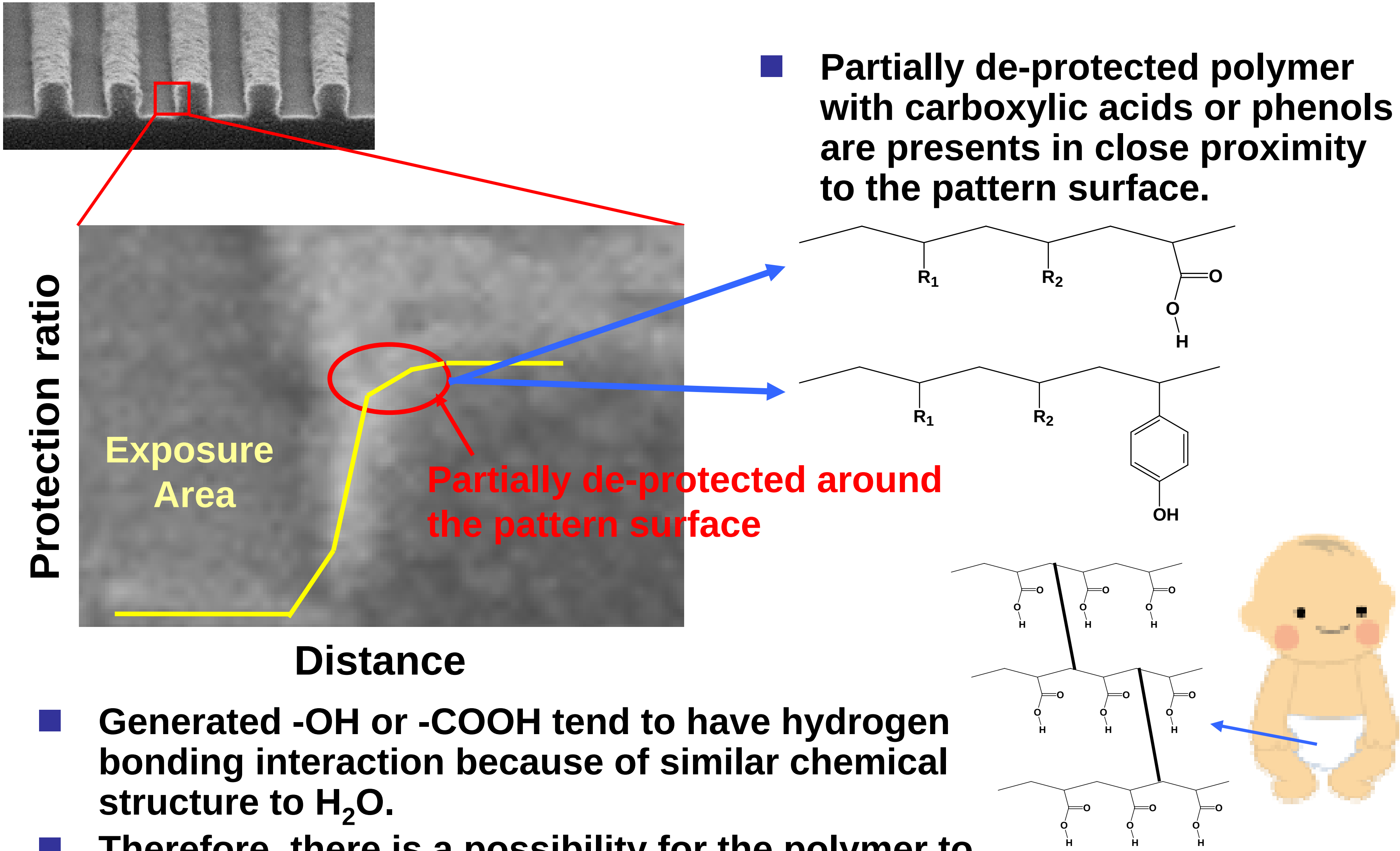
The lines meander and the length should be longer than straight line.

This phenomena might be cause from swelling.

“Softening layer model” may be large factor in smaller pattern.

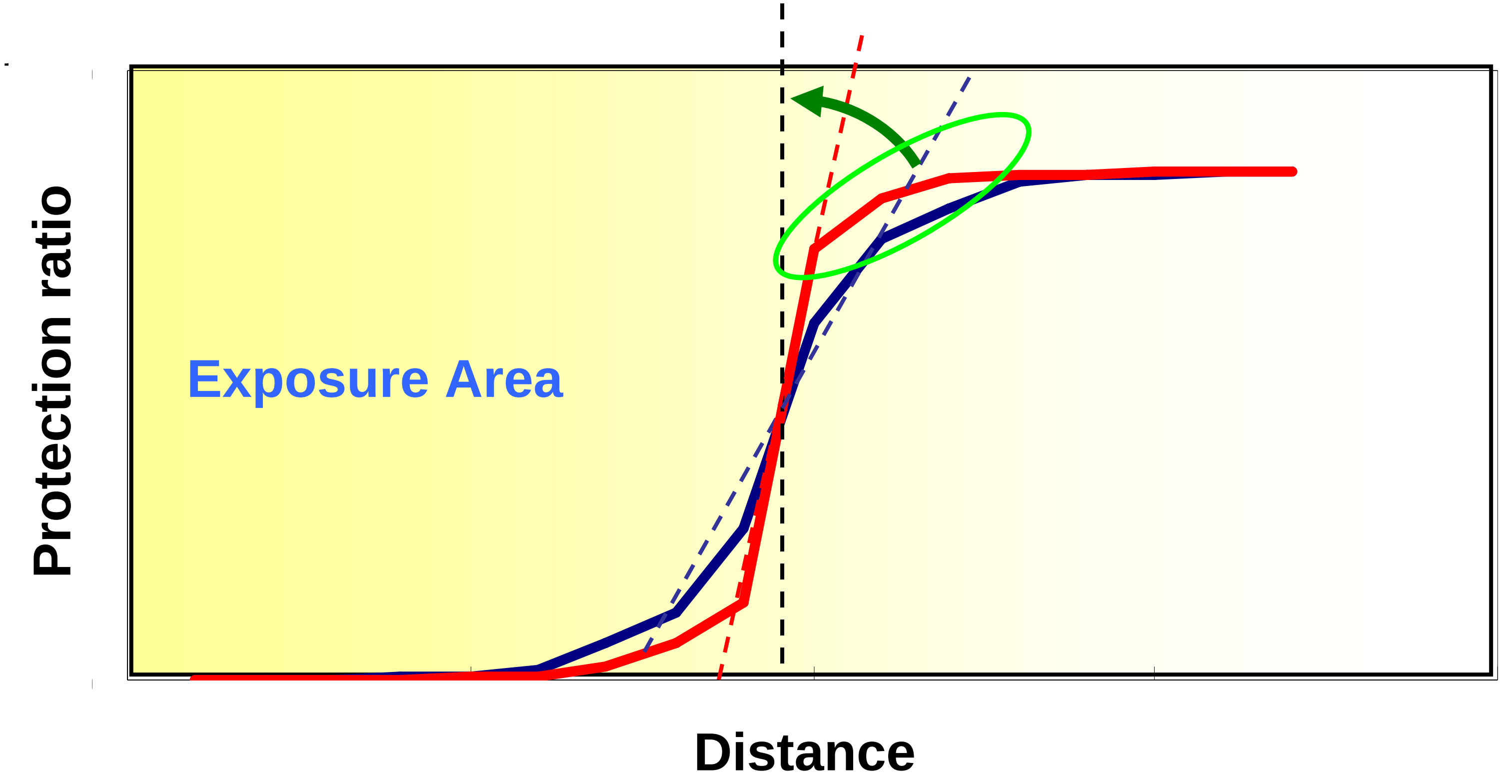
"Softening layer model" from chemical structure

- **Partially de-protected polymer with carboxylic acids or phenols are presents in close proximity to the pattern surface.**



- **Generated -OH or -COOH tend to have hydrogen bonding interaction because of similar chemical structure to H_2O.**
- **Therefore, there is a possibility for the polymer to retain rinse water.**

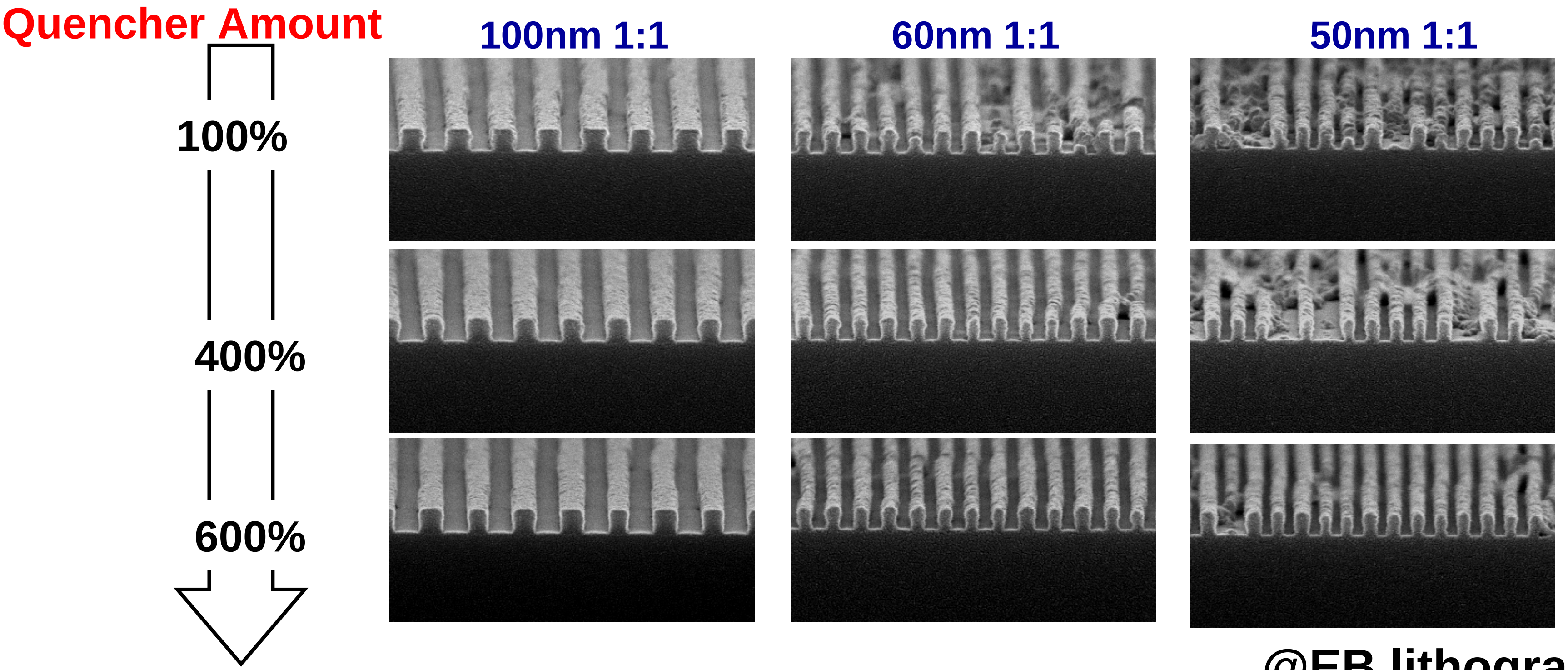
Approach for Reduction of "Softening layer model" effect from Resist Material



- We will need to reduce the presence of acid around the pattern surface to reduce the swelling.
- Enhancing contrast of protection ratio should have an effect on improving swelling = collapse

Approach for Reduction of “Softening layer model” effect from Quencher loading level

Evidence 1 :
Collapse margin of Quencher loading level dependency



@EB lithography

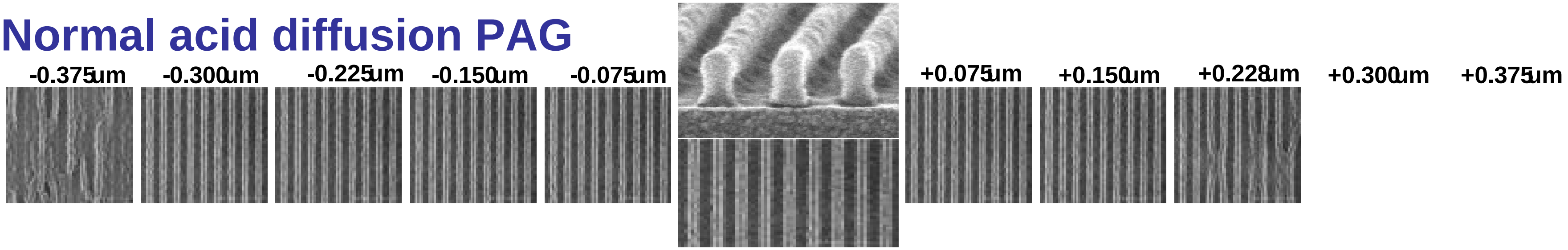
- **Increasing quencher loading level lead to**
  - Increased de-protection contrast
  - Improved collapse margin

Approach for Reduction of “Softening layer model” effect from acid diffusion length

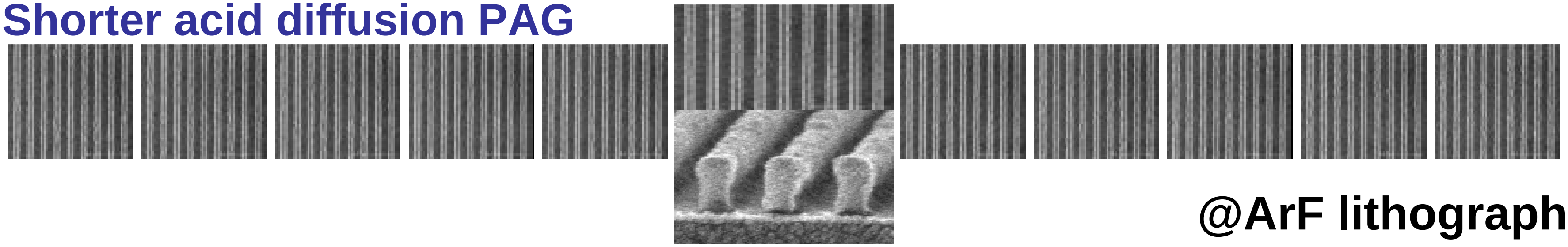
Evidence 2 :

Collapse margin comparison of acid diffusion dependency

Normal acid diffusion PAG



Shorter acid diffusion PAG



@ArF lithography

- **Shorter acid diffusion length PAG lead to**
  - **Increased de-protection contrast**
  - **Improved collapse margin**
    - ✓ **Although X-section profile seems to easily collapse.**

Summary and Discussion

Summary

- The aspect ratio will be very low for *hp*22nm generation and below .
- We are now trying to understand and improve the resist pattern collapse issue from the resist materials perspective.
- We believe that the resist swelling is one of the major contributors to the line collapse.

Discussion

- The aspect ratio will need to be 2 or below for *hp*22nm generation and below. The thickness of resist is expected to be 20~30nm for *hp*16nm generation.
- Will it be possible to etch with such thin film mask?
- Will we be able to use aqueous solution system in *hp*16nm generation?
- Candidates for alternative system? SCC? Organic solvent?