Approaches to address the EUV resist challenges of image collapse, LWR, sensitivity, and resolution

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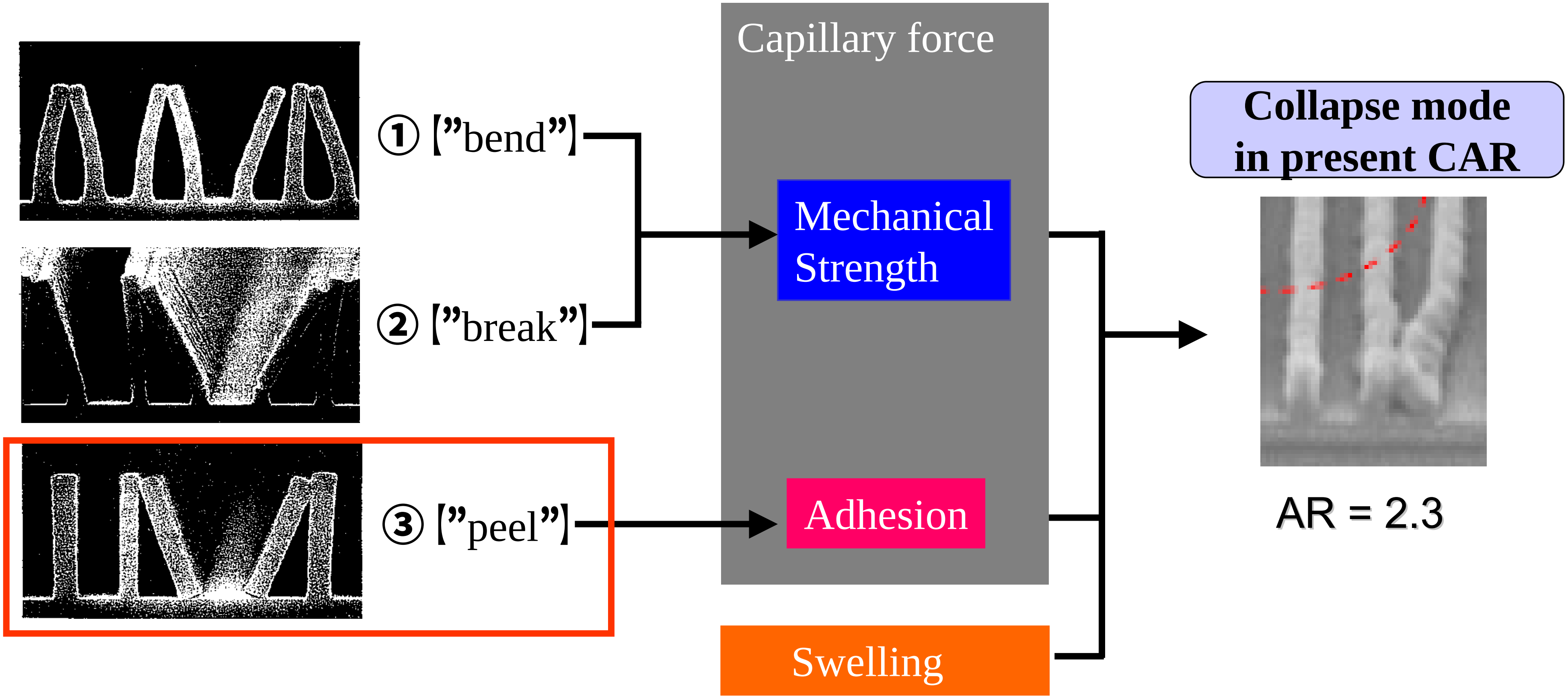
Outline

- ✓ Mechanism of resist collapse
- ✓ Technologies to fix resist collapse
- ✓ Discussion: trade-off relation, collapse and RLS
- ✓ Conclusions

Resist collapse

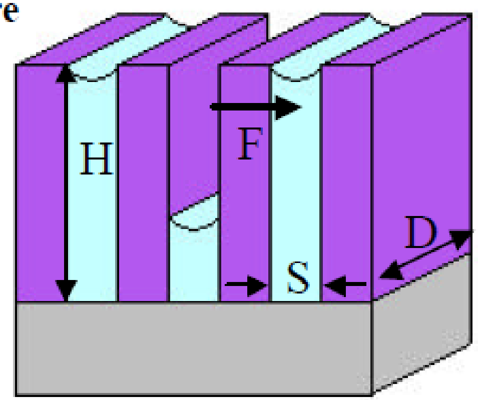


Physics of capillary force

Capillary Pressure

$$\Delta P = \frac{\gamma}{R}$$

$$R = \frac{S}{2\cos\theta}$$



$$F_1 = \Delta P * \Delta Area = \left(\frac{2\gamma\cos\theta}{S}\right) * HD$$

Balanced with….

Young's modulus (Mechanical strength)

Adhesion strength

ΔP: Capillary pressure gradient

γ: Surface tension

R: Radius of curvature

S: Spacing

θ: Contact angle of rinse liquid on resist surface

Blue box: Rinse liquid

Red box: Resist material

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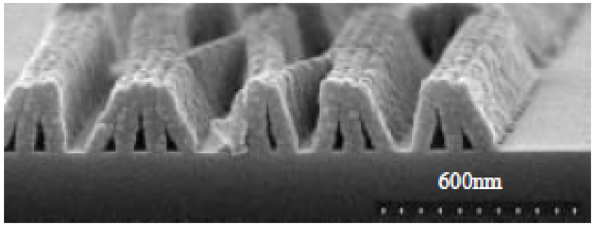
Super critical CO_2 development for collapse issue

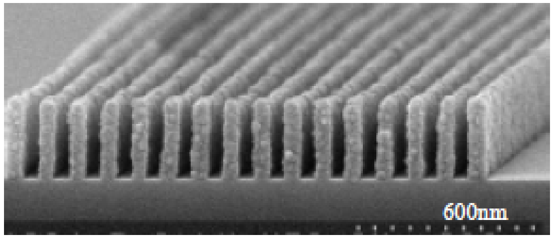
High mechanical strength / low capillary force are promising for collapse

	Conventional dry	Supercritical dry

60nm 1:1 L/S Thickness:250nm(aspect ratio>4)

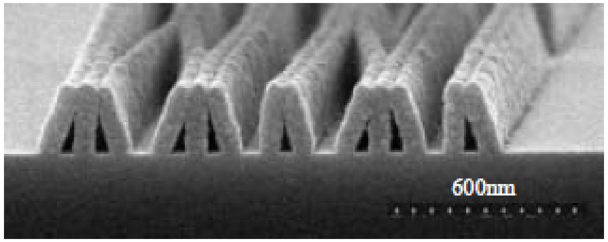
Tr = 250 nm

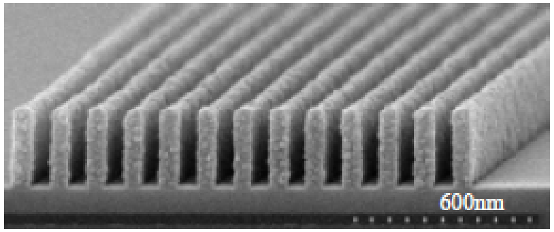




70nm 1:1 L/S Thickness:250nm(aspect ratio=3.6)

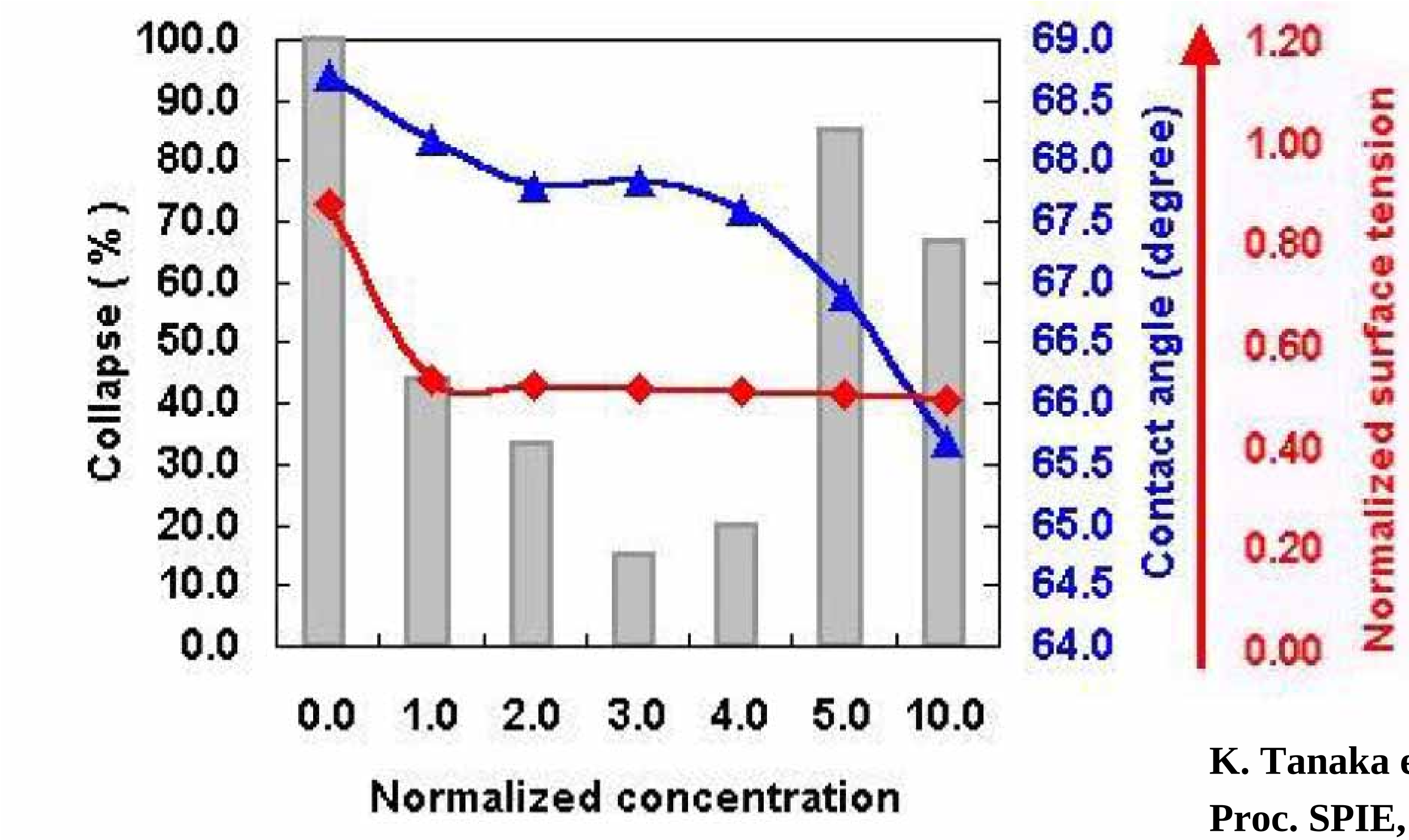
Tr = 250 nm





TMAH Development, X-linking type negative tone EB resist

FIRM process for collapse issue

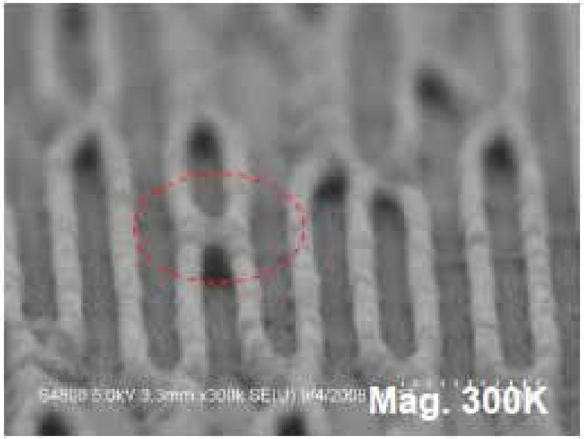


K. Tanaka et. al.,
Proc. SPIE, Vol. 5039 (2003) p1366.

Fig.12 Surface tension and contact angle to surfactant concentration
(surfactant: sample D ,248nm ESCAP type resist/Barc,130nm L/S, Aspect ratio;3.96)

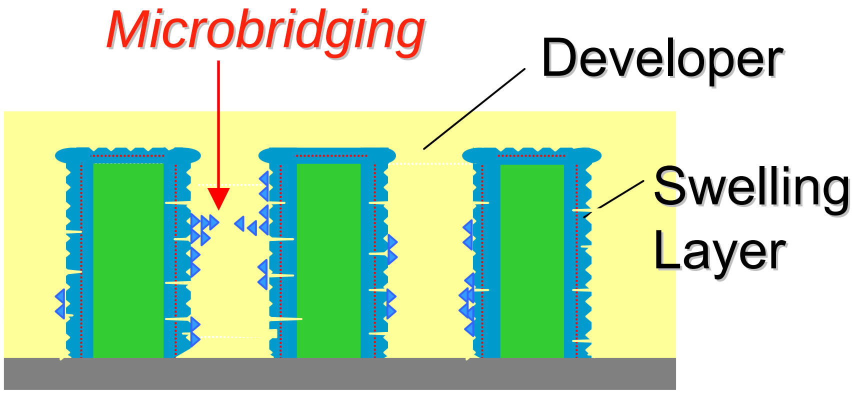
Swelling would also cause collapse

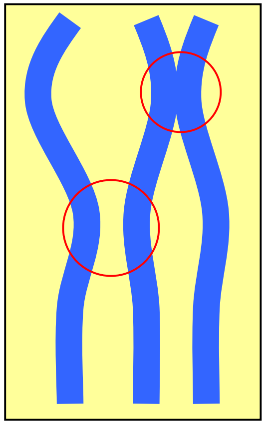
22 nm hp patterns



Data courtesy of SEMATECH

Positive tone EUV resist





Deformation of pattern might be occur by "swelling"

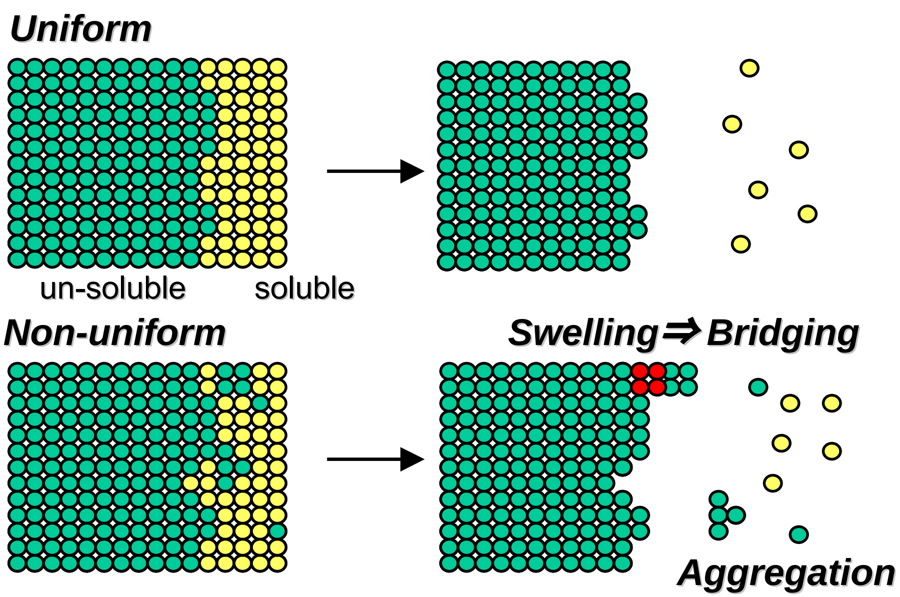
Design principles for low swelling resists

Design Principles

① Increasing rate of (ii) + (iii)

⇒ (i) < (ii) + (iii)

② Increasing uniformity in development



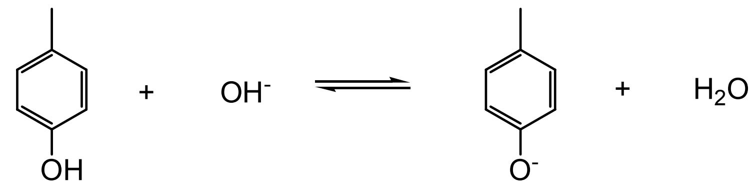
Development steps

(i) Penetration of developer into film

⇒Hydrophilic surface (polymer)

(ii) Acid-base equilibrium

⇒ High pKa acidic group (ionizaiton degree)



(iii) Solvation of polymer

⇒ Hydrophilic polymer

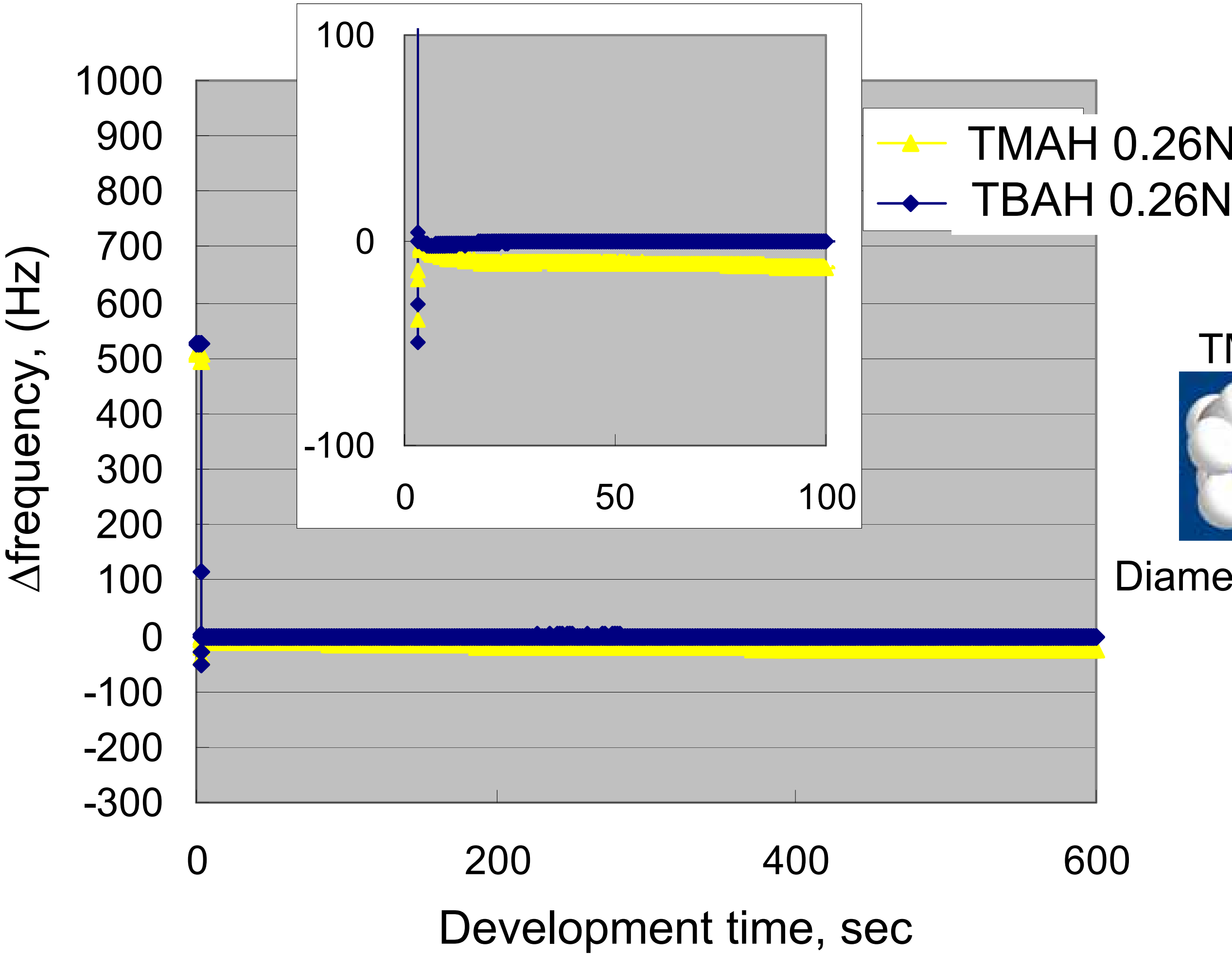
Low molecular weight polymer

Weak intermolecular interaction polymer

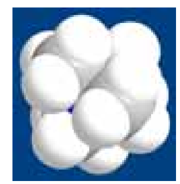
(iv) Diffusion into solvent layer

Penetration speed control with developer molecular size

TMAH (0.26N) ⇒ TBAH (0.26N)

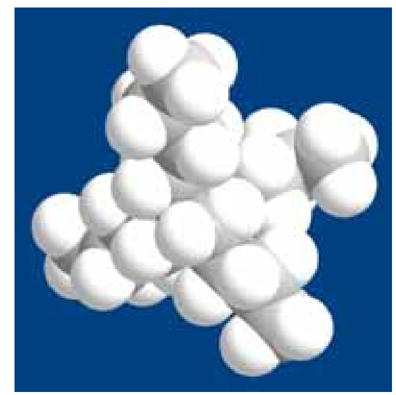


TMAH



Diameter ~ 4.2 Å

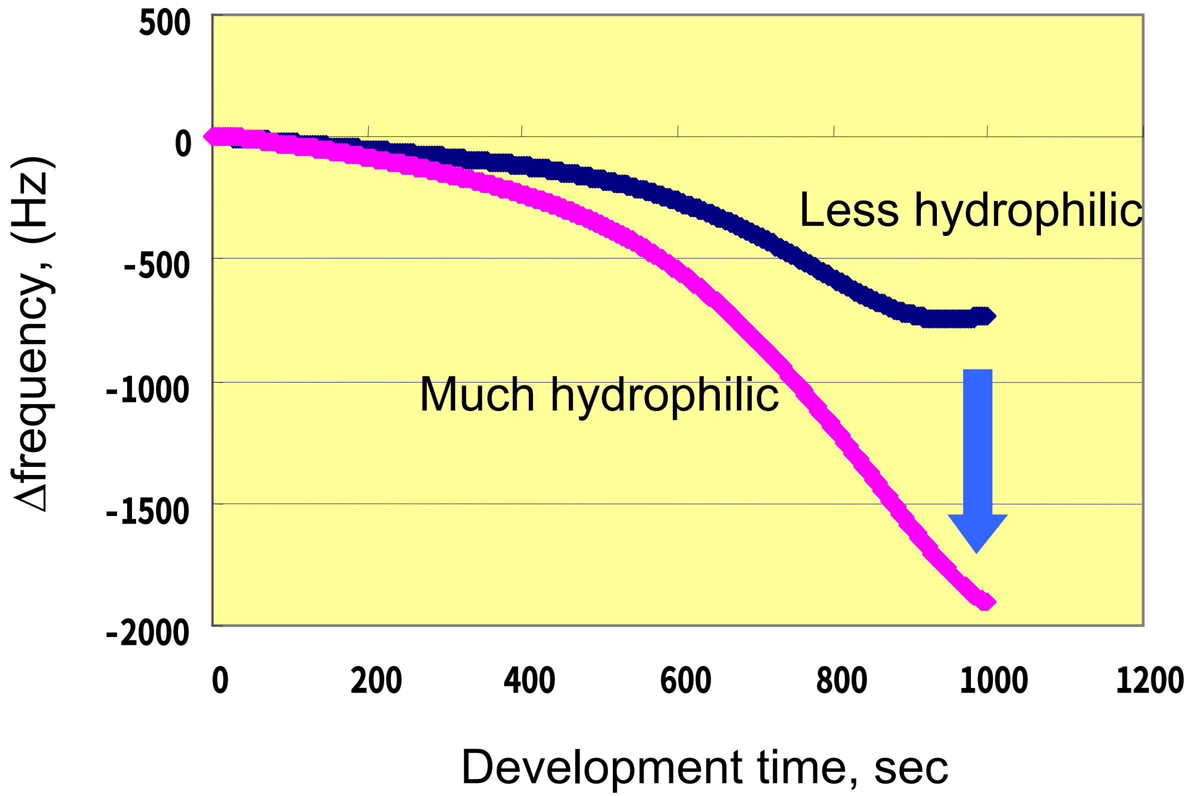
TBAH



Diameter ~ 10.6 Å

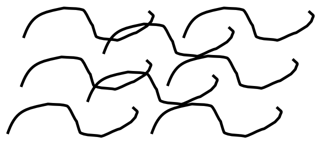
Penetration speed control with polymer hydrophilicity

Variation of hydrophilic monomer ratio in co-polymer



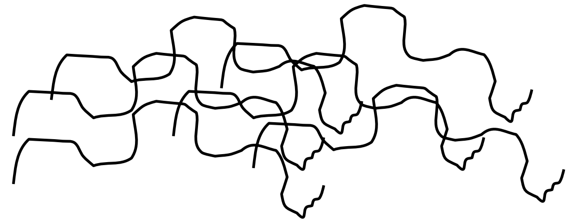
Solvation speed control with polymer Mw

Small Mw

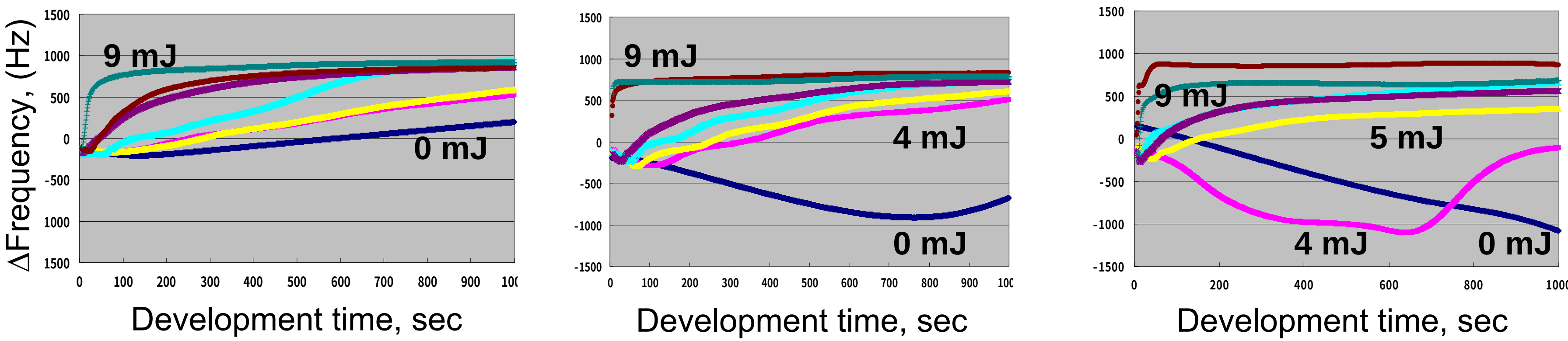


Less tangled
Easy to be solvated

Large Mw



Much tangled
Hard to be solvated



Small → Large

Polymer Mw

Non-alkaline developer

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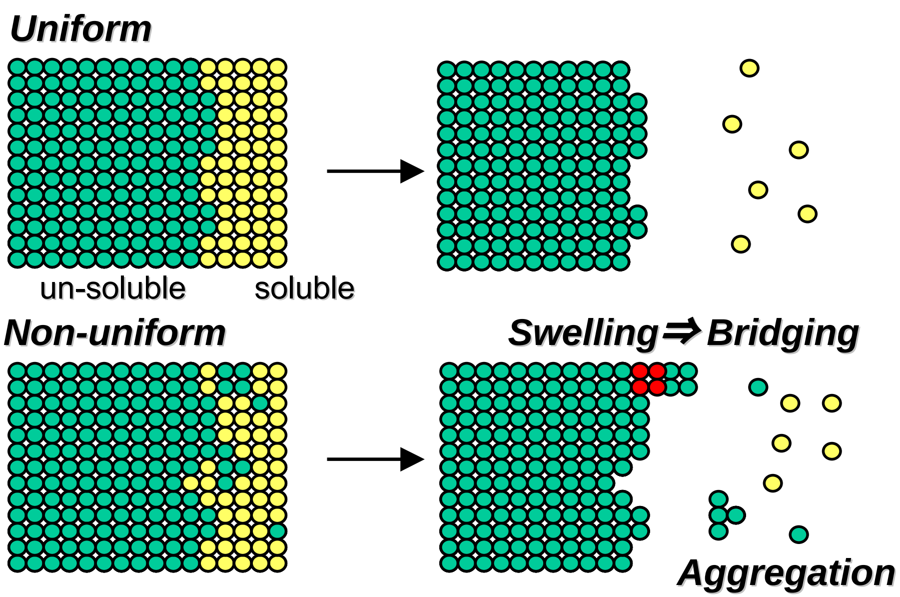
② Increasing uniformity in development



Development steps

<u>(i) Penetration of developer into film</u>

⇒Hydrophilic surface (polymer)

<u>(ii) Acid-base equilibrium</u>

⇒ High pKa acidic group (ionizaiton degree)

<u>(iii) Solvation of polymer</u>

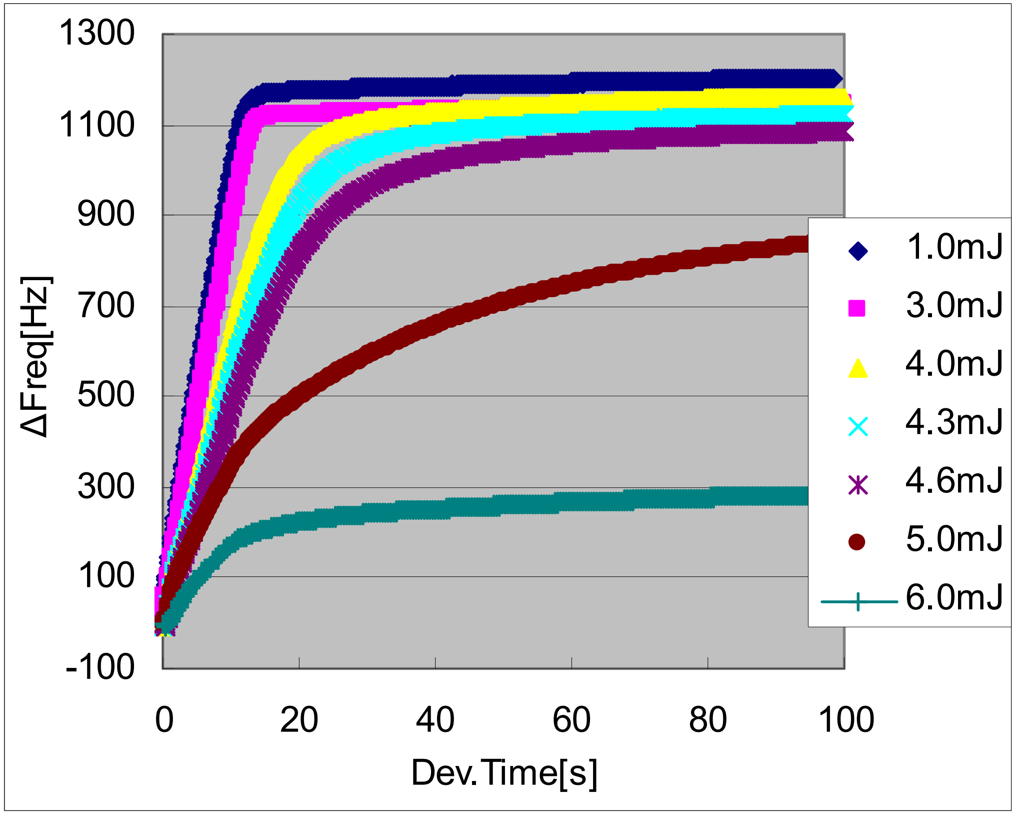
⇒ Hydrophilic polymer
Low molecular weight polymer
Weak intermolecular interaction polymer

<u>(iv) Diffusion into solvent layer</u>

Low swelling property with solvent type developer

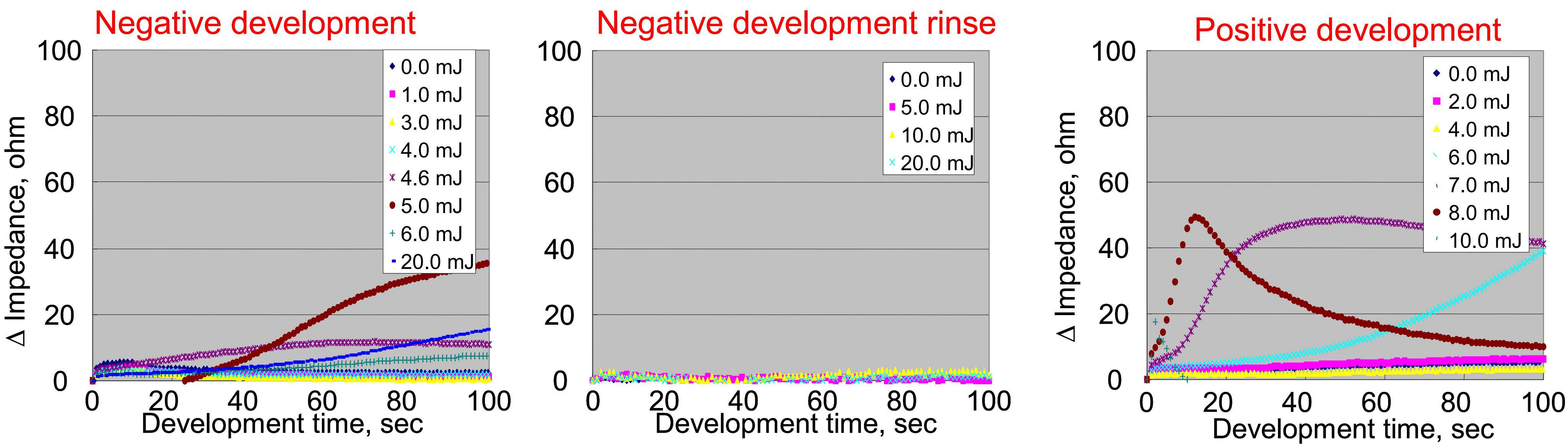
Low swelling character of negative tone development

QCM analysis result

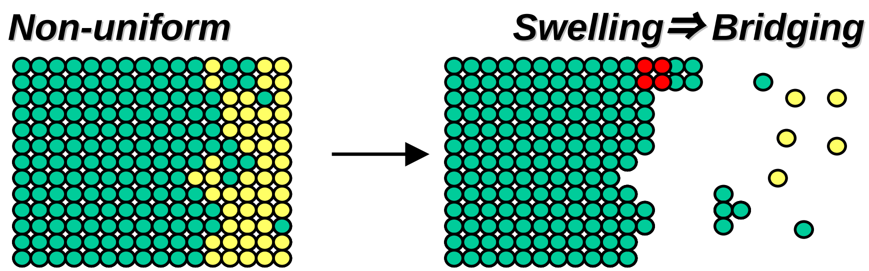


Resist: FAiRS-9101A12
Negative Dev.

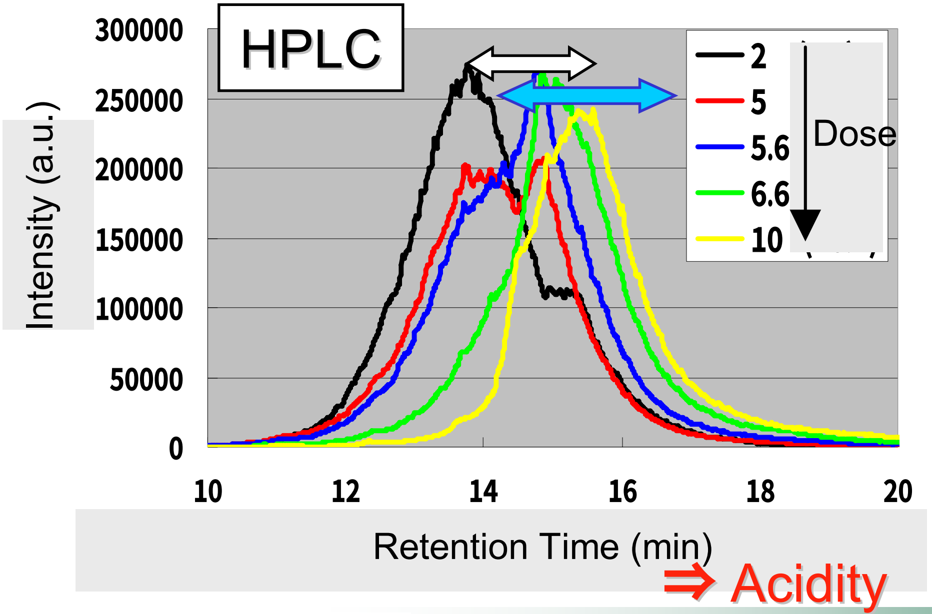
Low swelling character of negative tone development

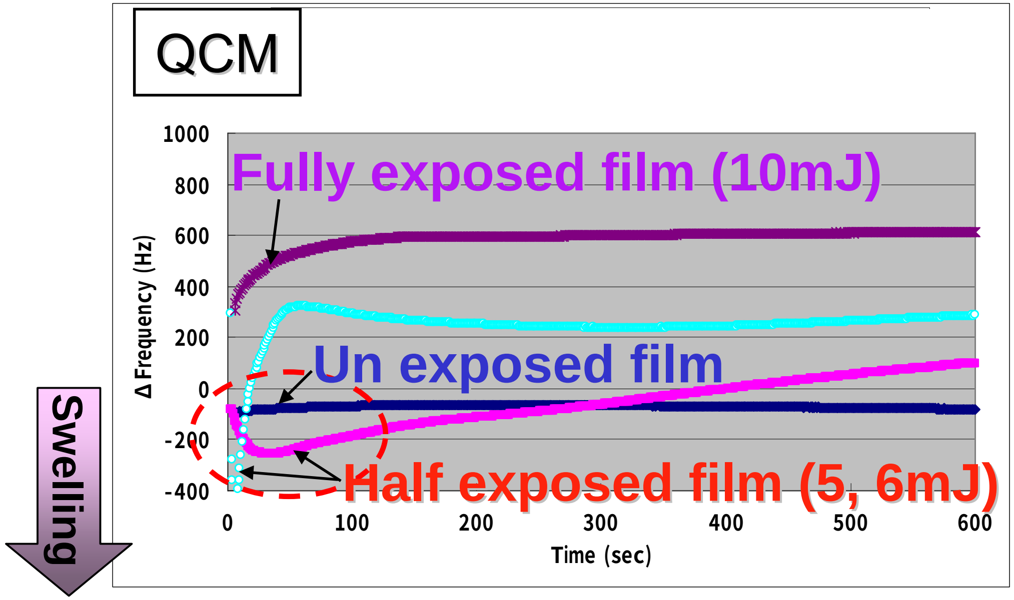


Non-uniform deprotection also causes swelling



Half-exposed area consists of mixture of polymers





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Trade-off relation between collapse and RLS

Addressing to collapse	Controlled property	Trade-off relation			Remark
		R	L	S	
scCO2 development	Surface tension	N	N	N	
FIRM rinse	Surface tension CA	N	N	N	
Hydrophobic resist	CA Swelling	N	(N)	N	Un-uniform dissolution property
TBAH developer	Swelling	N	N	N	
Small Mw polymer	Swelling	(N)	N	N	Smaller Tg
Organic developer	Swelling	(N)	N	N	Smaller dissolution contrast
Uniform de-protection	Swelling	N	N	N	

Basically, there's no trade-off relation between collapse and RLS.

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Conclusions

✓ Capillary force is a major factor in collapse.

Reducing surface tension, increasing contact angle, and suppressing swelling property are effective to fix collapse.

✓ Basically, there would be no trade-off relation between collapse and RLS performance.