

Resist Materials Issues beyond 22 nm-hp Patterning for EUV Lithography

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FUJIFILM Corporation

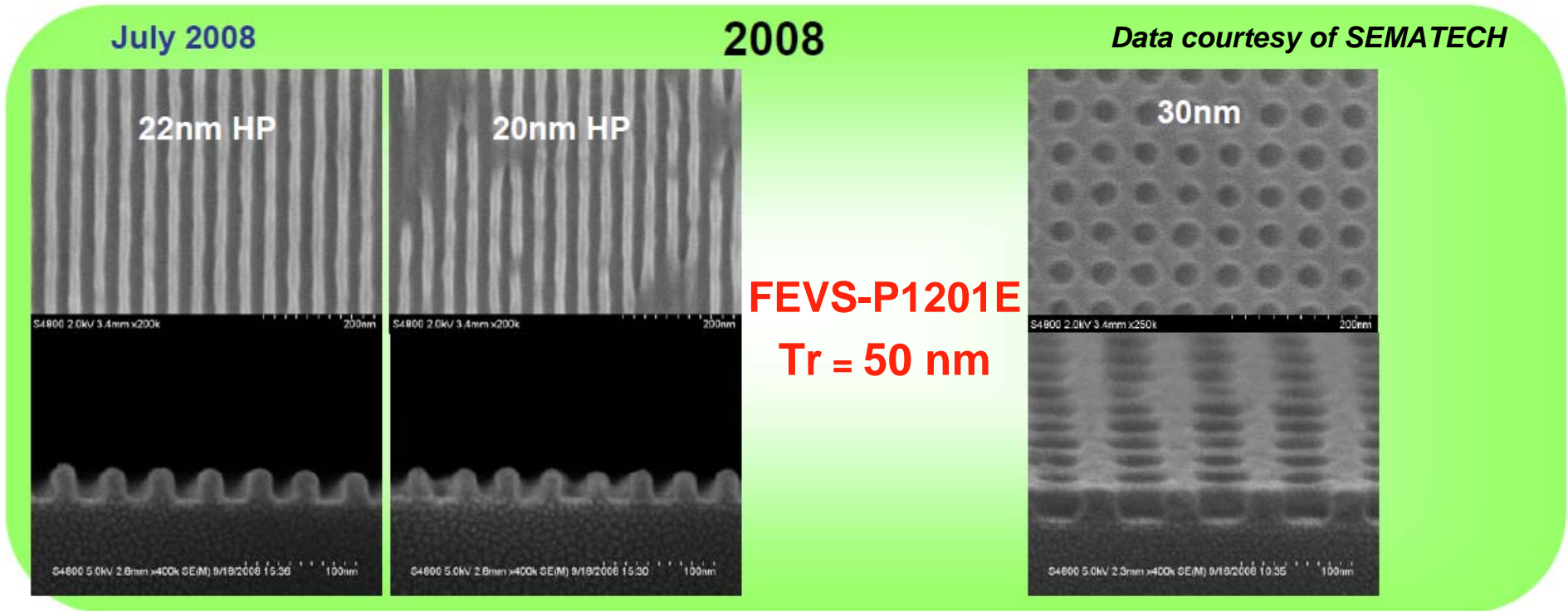
Research & Development Management Headquarters

Electronic Materials Research Laboratories

Outline

- ✓ Current status of CAR EUV resists
- ✓ Pattern Collapse
- ✓ Microbridging
- ✓ Conclusions
- ✓ Acknowledgements

Current CAR EUV Resists

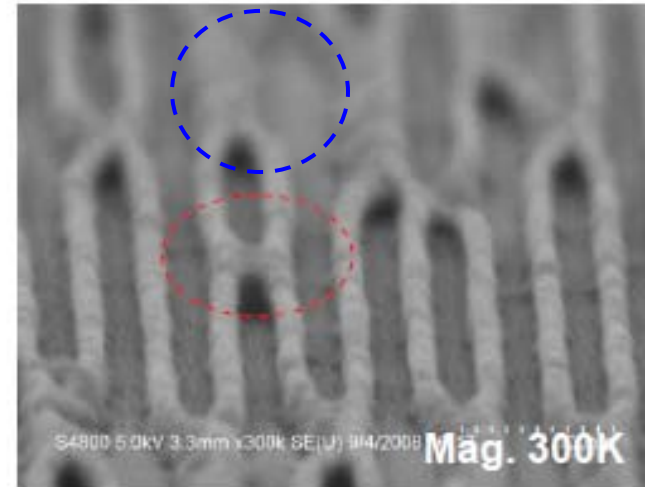
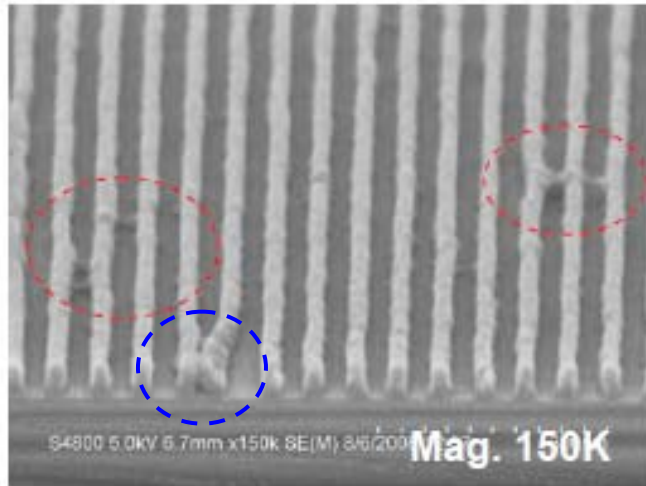


	Resolution	LWR	Sensitivity	Collapse (AR)
ITRS HVM Specs	22 (nm)	< 2.2 (nm)	< 10 (mJ/cm ²)	> 2.5
FEVS-P1201E	22 (nm)	5.6 (nm)	14.5 (mJ/cm ²)	2.3

Problems with CAR for Resolution

22 nm hp **Tr = 50 nm**

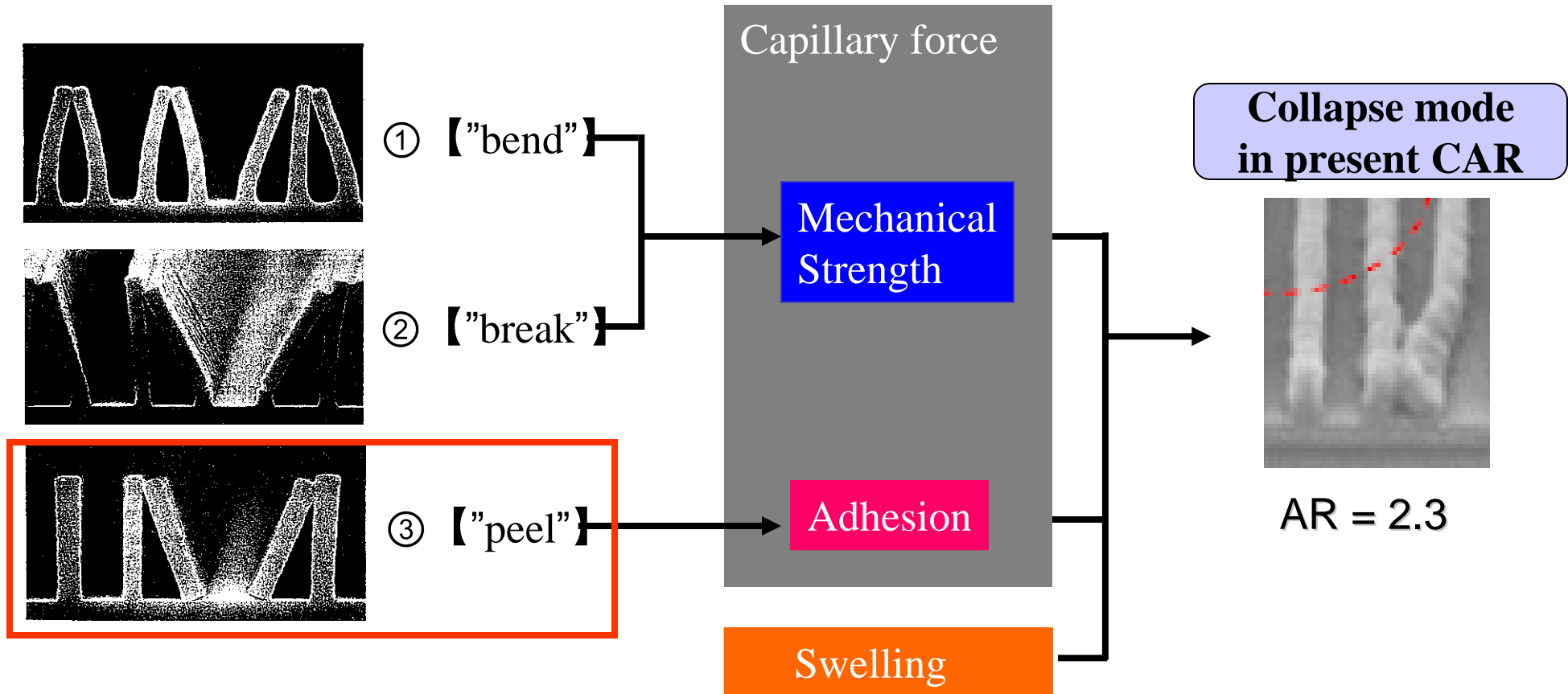
Data courtesy of SEMATECH
FEVS-P1201E



Target Resolution < 22 nm 1:1 Lines

- ✓ Profile
 - ✓ **Pattern Collapse**
 - ✓ **Microbridging**
 - ✓ Process Margin (CD Uniformity)
- } Large impact !**

CAR Resist Collapse

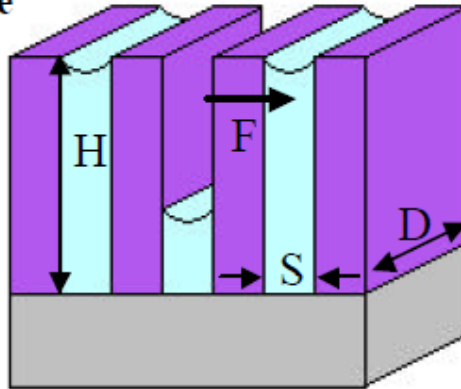


Physics of Capillary Force

Capillary Pressure

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

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



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

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

: Rinse liquid

: Resist material

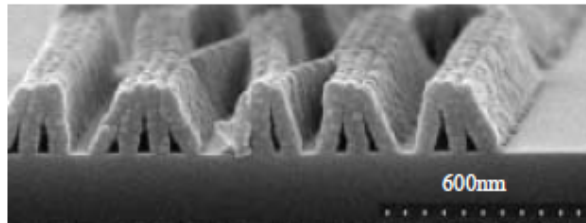
Neagtive Tone Resists with scCO2 Dry for Collapse Issue

High mechanical strength / low capillary force are promising for collapse

Conventional dry

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

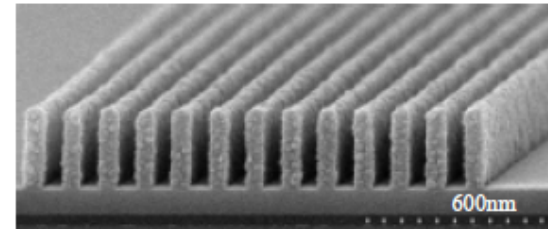
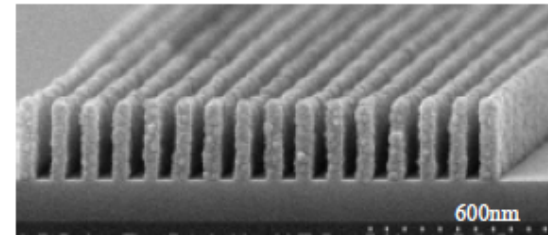
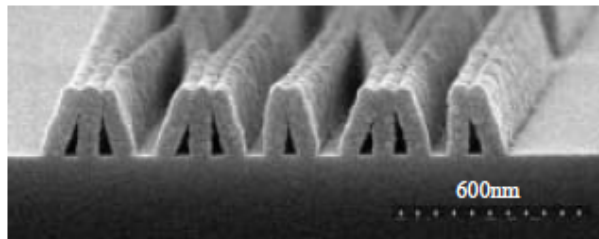
Tr = 250 nm



Supercritical dry

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

Tr = 250 nm



TMAH Development, [X-linking type negative tone EB resist](#)

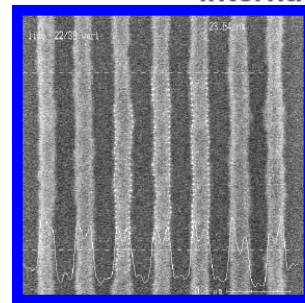
Neagtive Tone Resists Demonstrate 30 nm-hp Patterning on E-beam



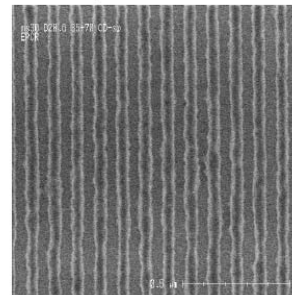
PLATFORM : PROCESS and DEMO

□ Process development

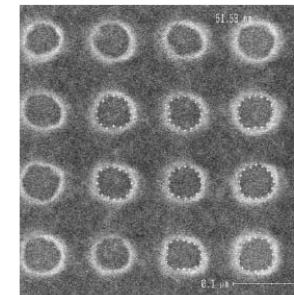
- Process development for sub32nm hp technology in relationships with resist suppliers
- Technology assessment
 - Pro/con of each technology versus ITRS targets
 - Benchmark European technologies versus international competition



Negative CAR
30nm hp - CD : 23nm



Positive CAR
35nm hp



Positive CAR
50nm hp

*Negative tone
Fujifilm EB resist*

Exposures performed on VISTEC SB 3054DW

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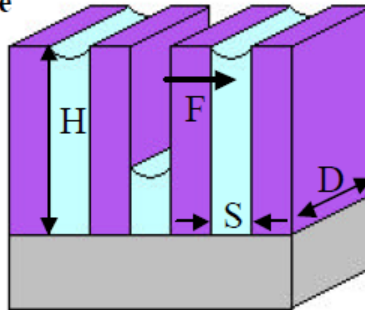
Similarities of EUV and EB promise the resolution below hp 30 nm on EUV

Comparison between EUV and ArFi resists

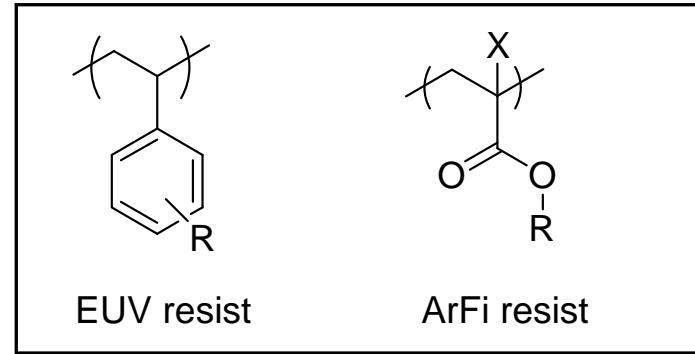
Capillary Pressure

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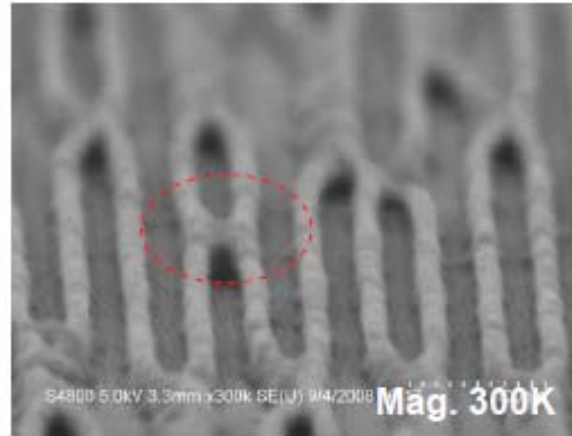


Resist	Half pitch	Critical A.R.	$2\gamma\cos\theta$ (rel.)	Swelling	Mechanical strength
EUV resist FEVS-P1201E (Styrene resin)	22 nm	2.3	2	<i>Not enough ?</i>	?
Optimal ArFi resist (Acrylic resin)	46 nm	3.0	1	<i>Not enough ?</i>	?
Negative tone resist (X-linking type) x scCO2 dry	60 nm	>> 4	~ 0	<i>Not enough ?</i>	High ?

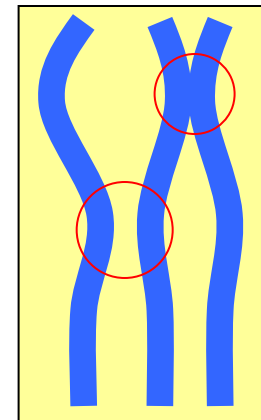
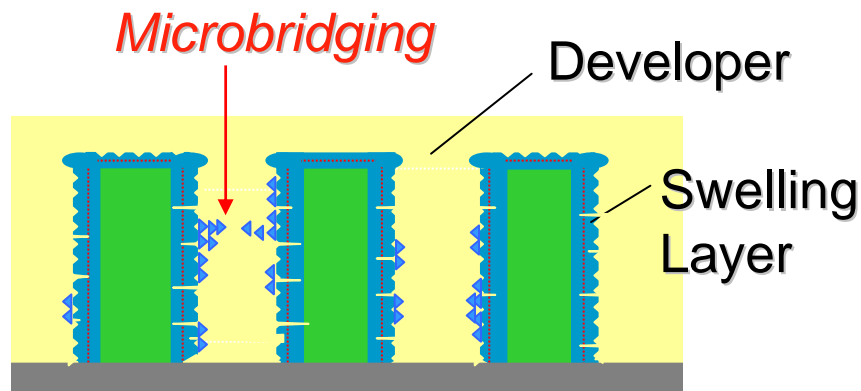
Further control should be required on “surface tension /contact angle” and “swelling”.

Microbridge Formation Dominated by Swelling in Development

22 nm hp
patterns



Data courtesy of SEMATECH
Positive tone EUV resist

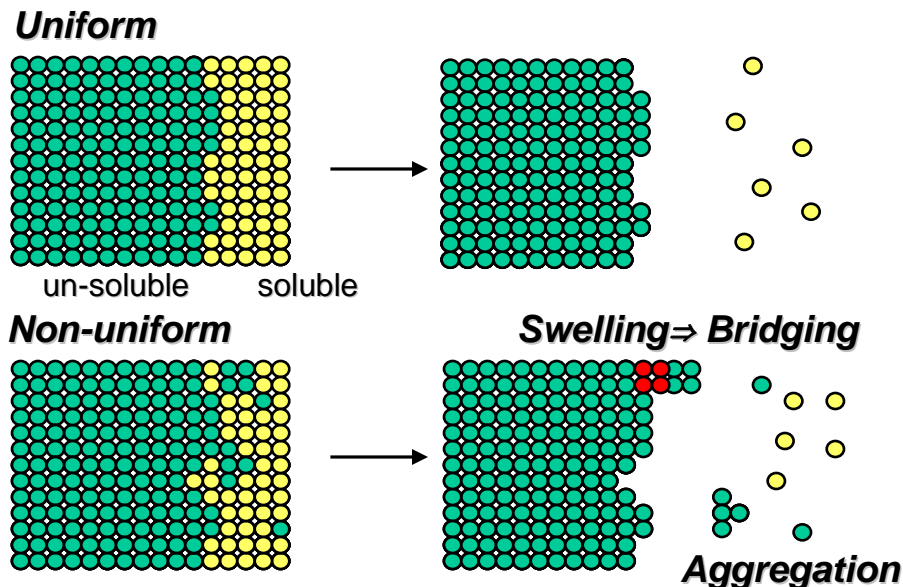


Deformation of pattern
might be occur by "swelling"

Design Principles for Low Swelling Resists

Design Principles

- ① Increasing rate of (ii) + (iii)
⇒ (i) < (ii) + (iii)
- ② Increasing uniformity
in development



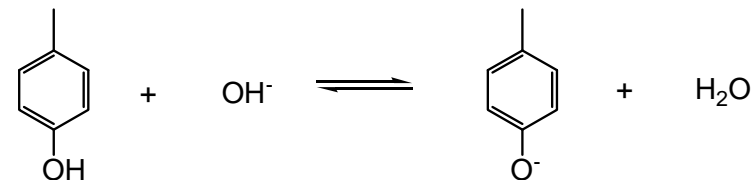
Development steps

(i) Penetration of developer into film

⇒ Hydrophilic surface (polymer)

(ii) Acid-base equilibrium

⇒ High pKa acidic group (ionization degree)



(iii) Solvation of polymer

⇒ Hydrophilic polymer

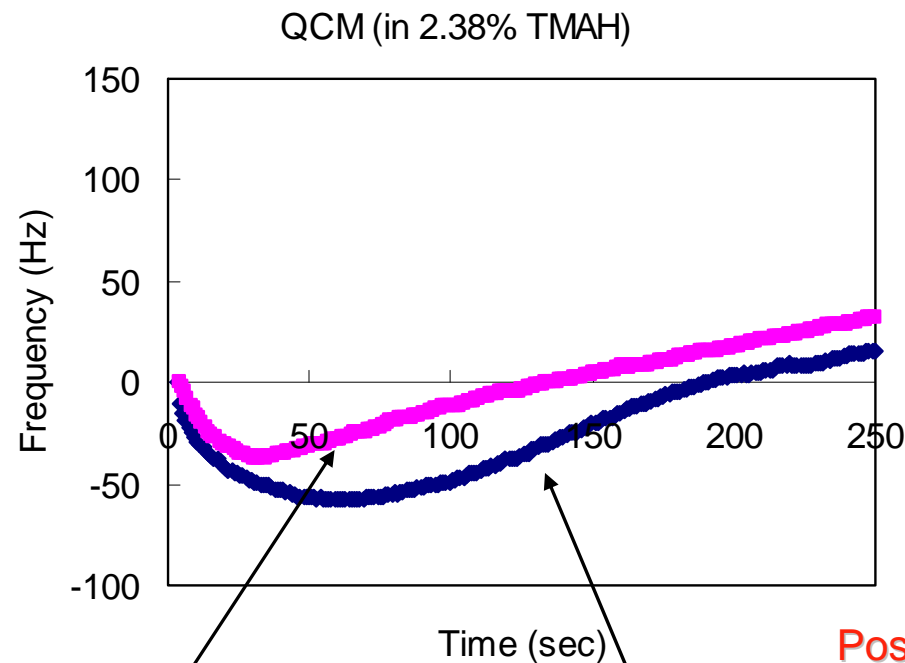
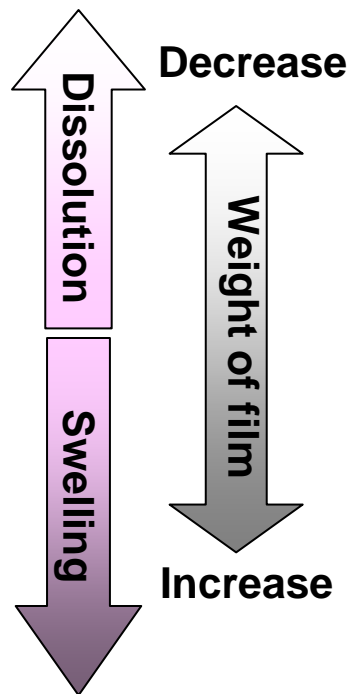
Low molecular weight polymer

Weak intermolecular interaction polymer

(iv) Diffusion into solvent layer

Microbridge Suppression using a Polymer with Controlled Hydrophilicity

QCM Analysis

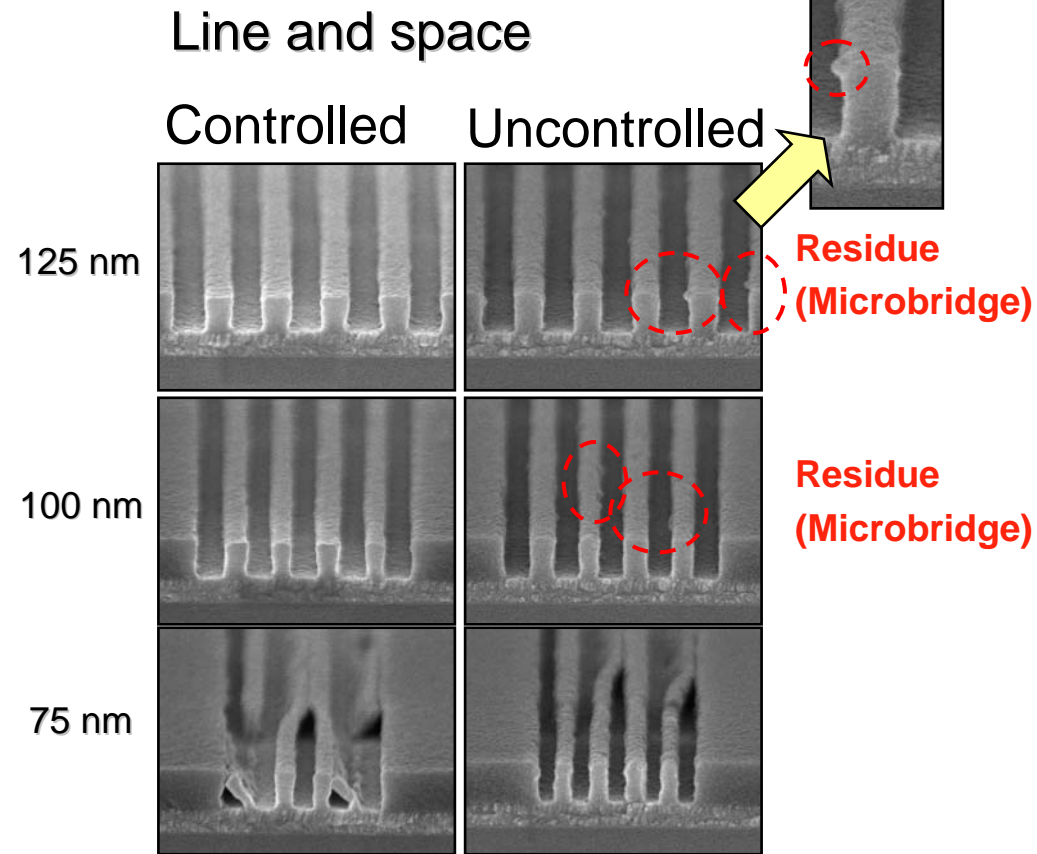
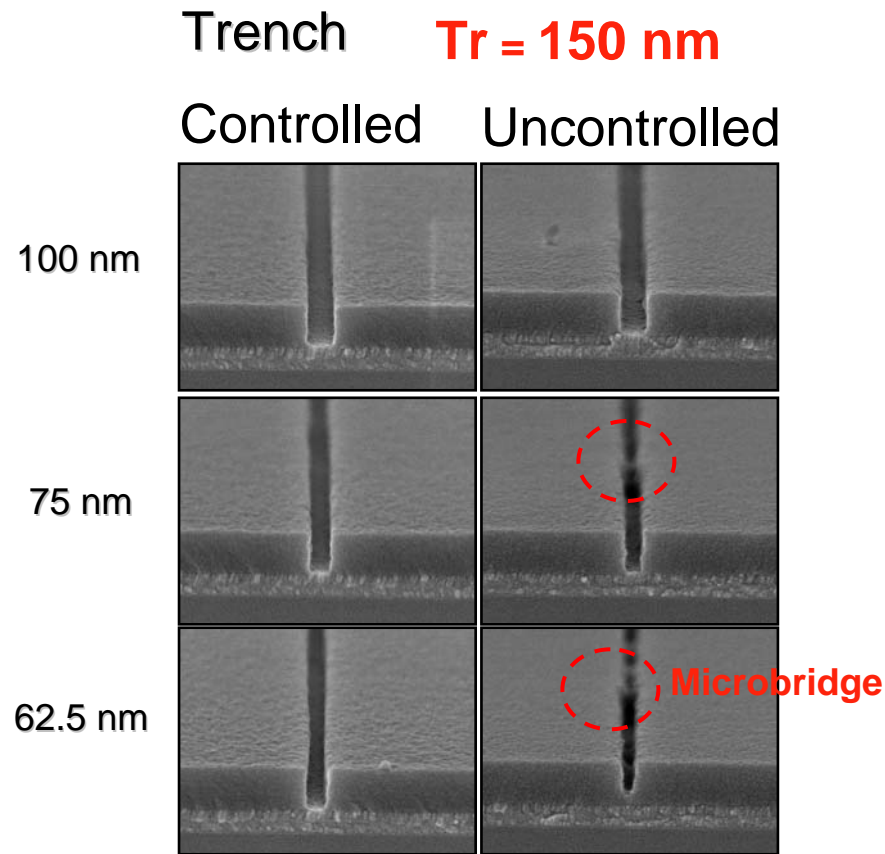


Positive tone EUV resists

Controlled PHS polymer
Dissolution > Penetration

Uncontrolled PHS polymer
Dissolution < Penetration

Microbridge Suppression using a Polymer with Controlled Hydrophilicity

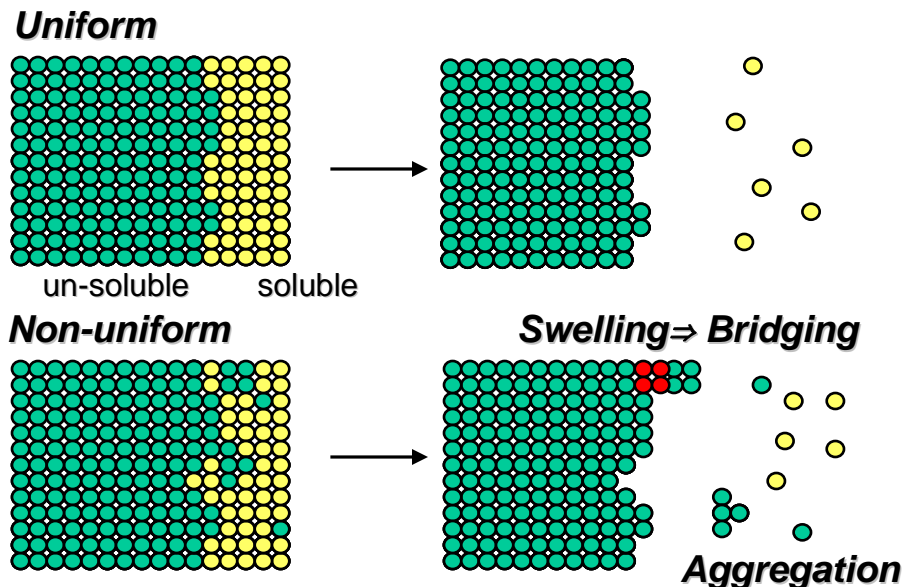


E-beam exposure (50 keV)
 TMAH Development, Positive tone EUV resists

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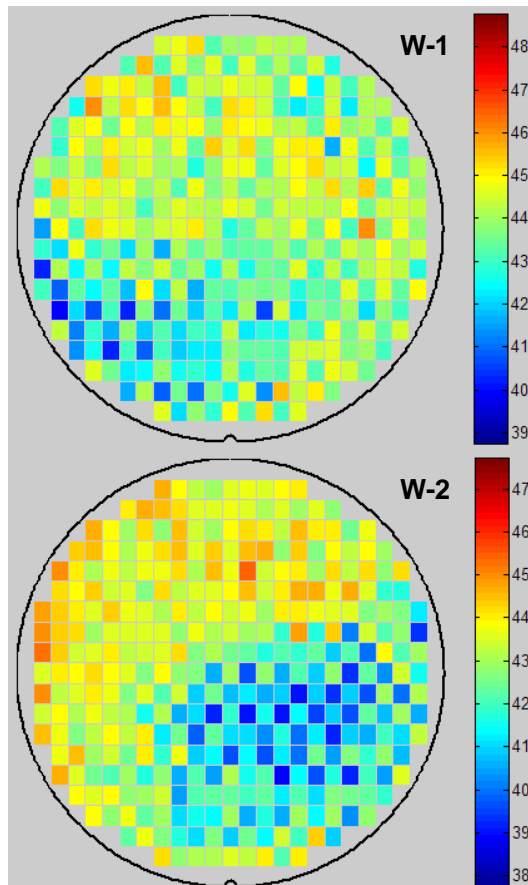
(iv) Diffusion into solvent layer

NTD is a Good Choice for Low Swelling

Tarutani et al., SPIE 2009, 7273-11.

NTD

Developer: FN-DP001
Dynamic dev.-1



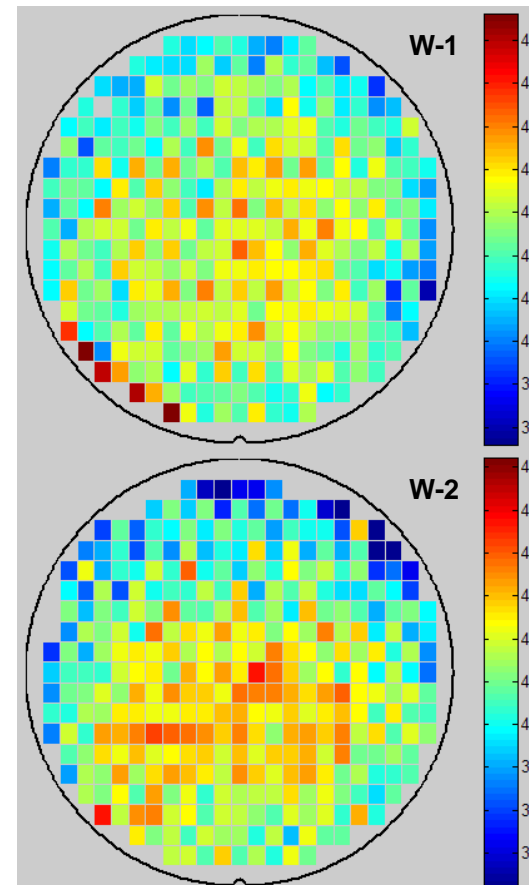
45nm trench
 128nm pitch
 NA1.2
 dipole illumination

NTD	PTD
Mean	
43.8 nm	42.6 nm
3 x STD dev.	
3.3 nm	4.0 nm

Mean	
42.7 nm	41.2 nm
3 x STD dev.	
4.2 nm	5.1 nm

PTD

Developer: OPD5262
Dynamic dev.-2

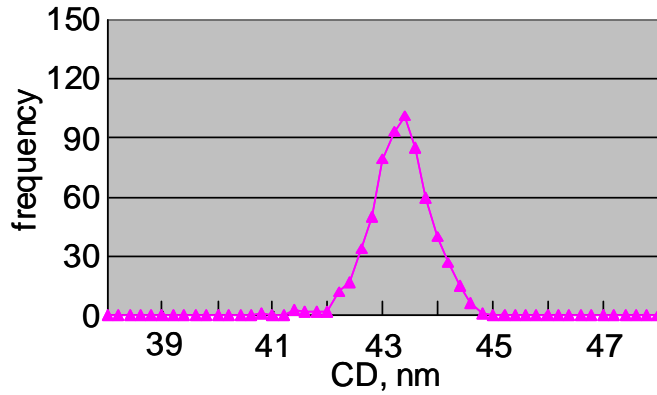


NTD is a Good Choice for Low Swelling

Tarutani et al., SPIE 2009, 7273-11.

NTD

Developer: FN-DP001
Dynamic dev-1.



43 nm trench
90 nm pitch
NA1.35
dipole illumination

NTD

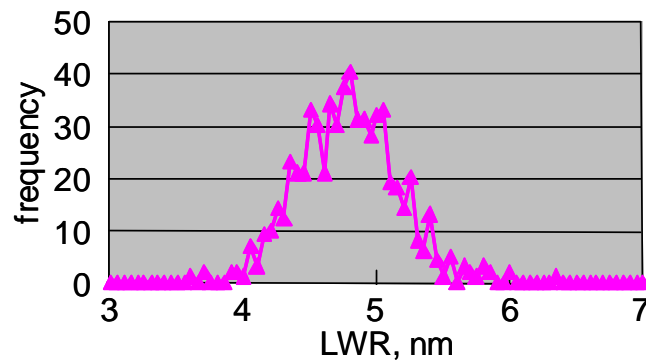
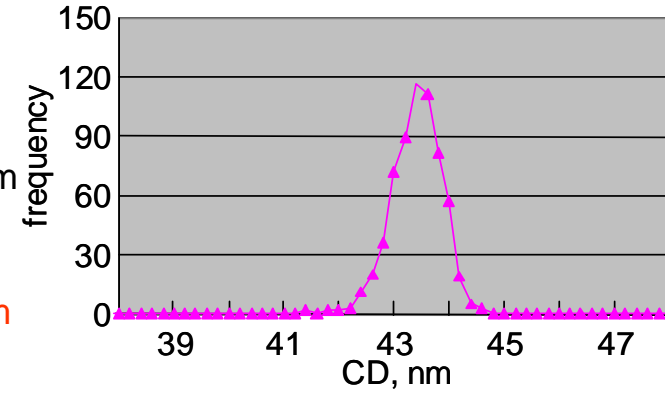
Mean
43.2 nm
3 x STD dev.
1.6 nm

PTD

Mean
43.3 nm
3 x STD dev.
1.4 nm

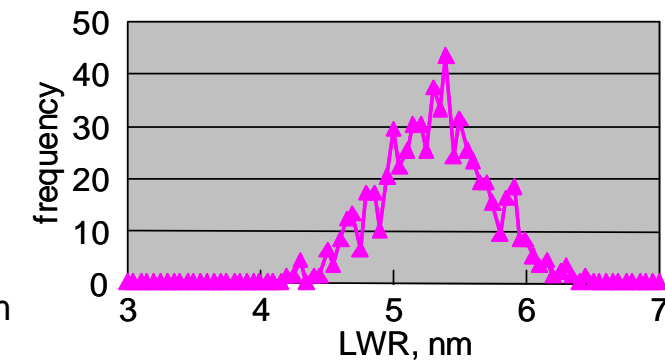
PTD

Developer: OPD262
Static dev.

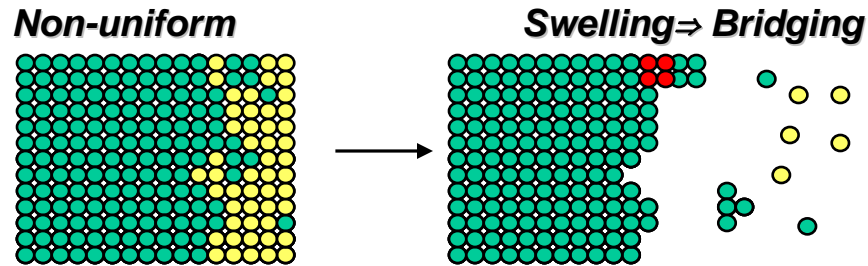


Mean
4.8 nm
3 x STD dev.
1.1 nm

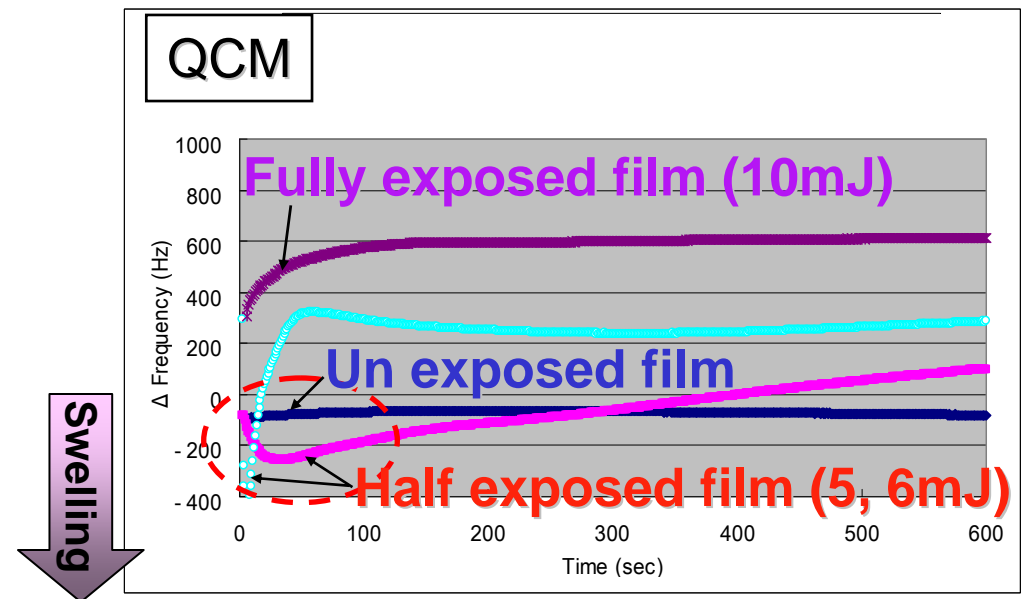
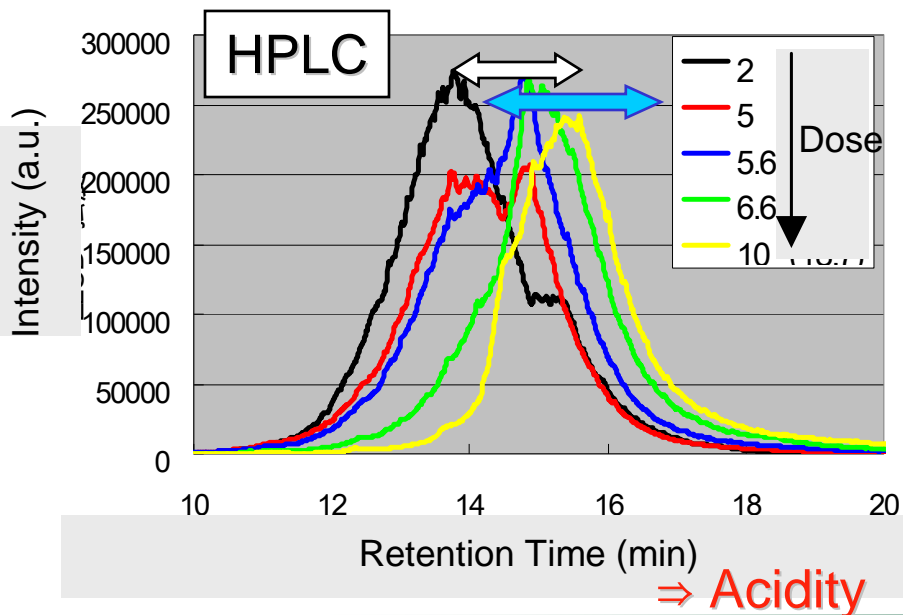
Mean
5.3 nm
3 x STD dev.
1.2 nm



Non-uniform Deprotection also Causes Swelling



Half-exposed area consists of mixture of polymers



Conclusions

- ✓ CAR resists demonstrate 22 nm-hp patterning, but pattern collapse and microbridging restrict their resolution.
- ✓ Capillary force is a major factor to improve collapse. Negative tone resist with low surface tension rinse might be a promising candidate for sub 20 nm-hp patterning.
- ✓ Microbridging is dominated by swelling and limits resolution of positive tone CAR resists.
- ✓ Optimization of polymer solubility enhance resolution at least on E-beam exposure. Uniform deprotection, development and rinse should cause further enhancement on resolution.

Acknowledgements

Chawon Koh at SEMATECH

Thank you for your kind attention !