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

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Outline

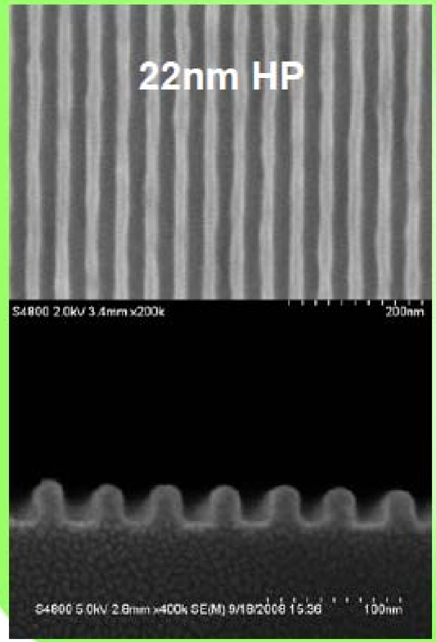
- ✓Current status of CAR EUV resists
- ✓Pattern Collapse
- ✓Microbridging
- ✓Conclusions
- ✓Acknowledgements

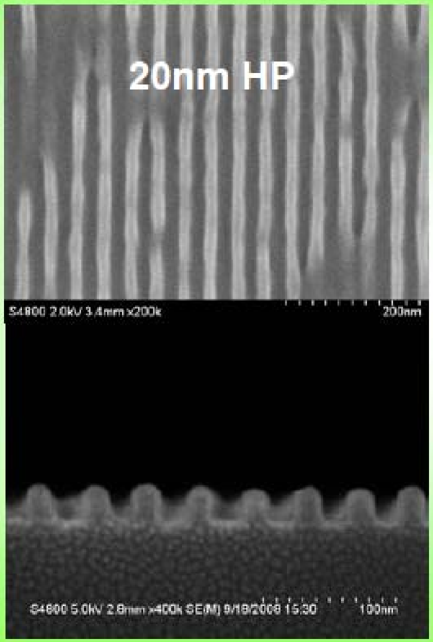
Current CAR EUV Resists

July 2008

2008

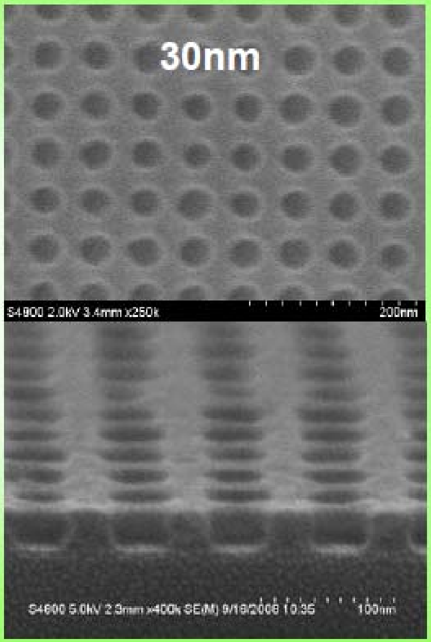
Data courtesy of SEMATECH





FEVS-P1201E

Tr = 50 nm

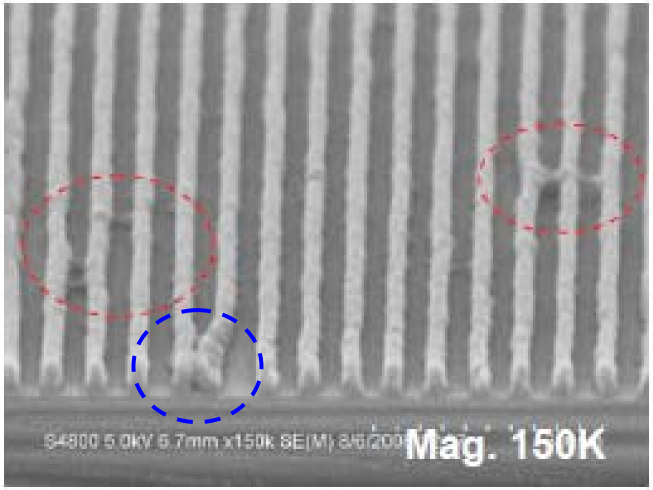


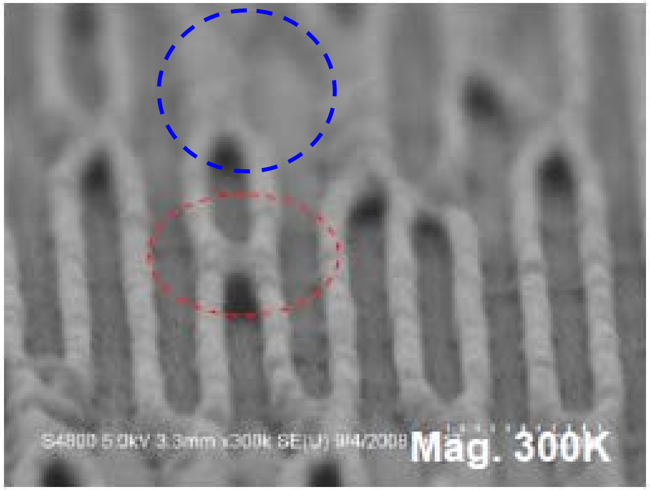
	Resolution	LWR	Sensitivity	Collapse (AR)
ITRS HVM Specs	22 (nm)	< 2.2 (nm)	< 10 (mJ/cm^2)	> 2.5
FEVS-P1201E	22 (nm)	5.6 (nm)	14.5 (mJ/cm^2)	2.3

Problems with CAR for Resolution

22 nm hp **Tr = 50 nm**

Data courtesy of SEMATECH
FEVS-P1201E



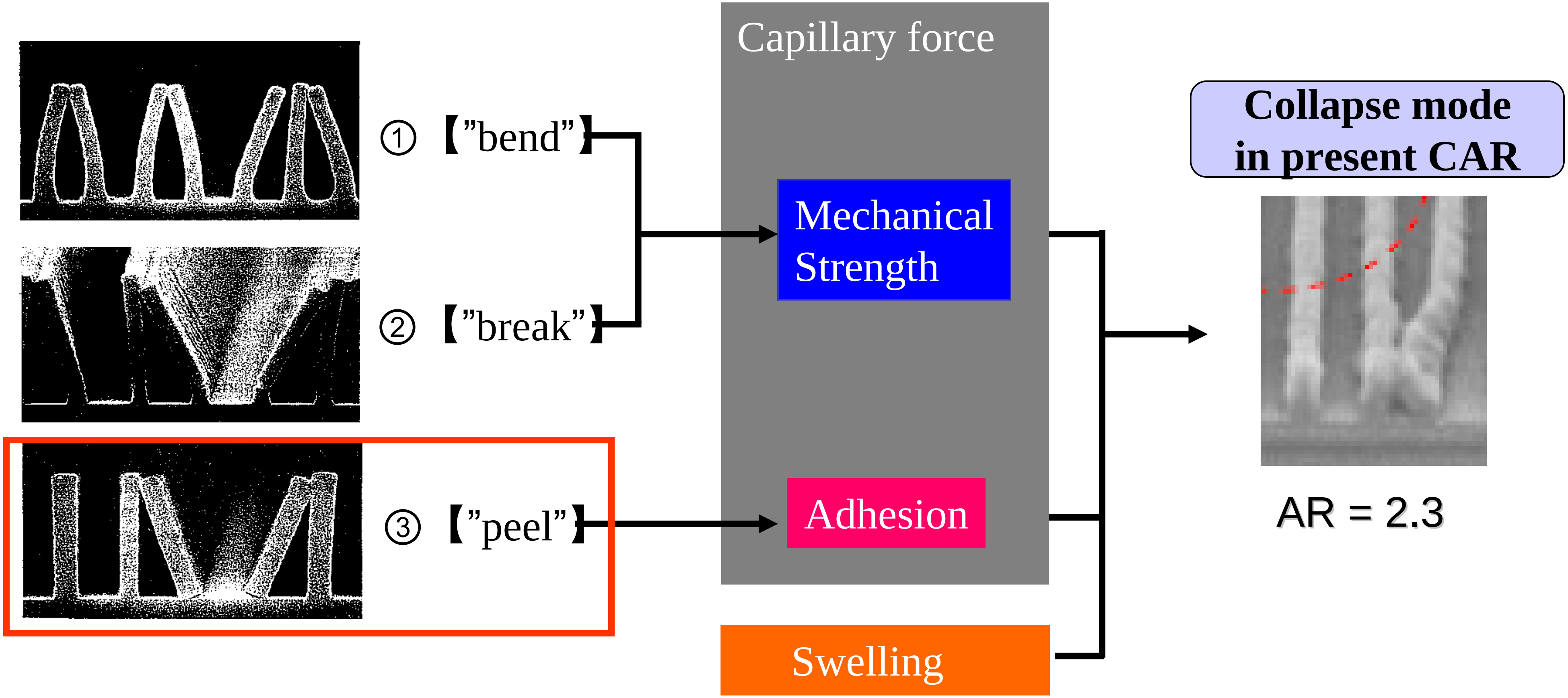


Target Resolution < 22 nm 1:1 Lines

- ✓Profile
- ✓Pattern Collapse
- ✓Microbridging
- ✓Process Margin (CD Uniformity)

} *Large impact !*

CAR Resist Collapse



① 【”bend”】

② 【”break”】

③ 【”peel”】

Capillary force

Mechanical Strength

Adhesion

Swelling

Collapse mode in present CAR

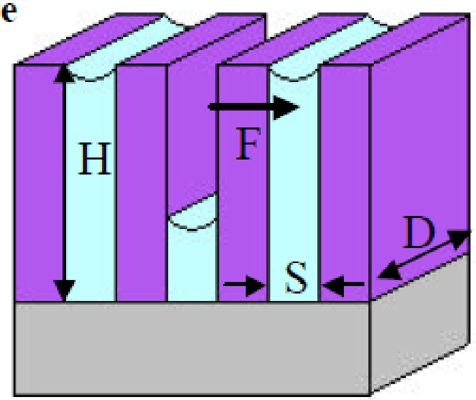
AR = 2.3

Physics of Capillary Force

Capillary Pressure

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

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



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

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

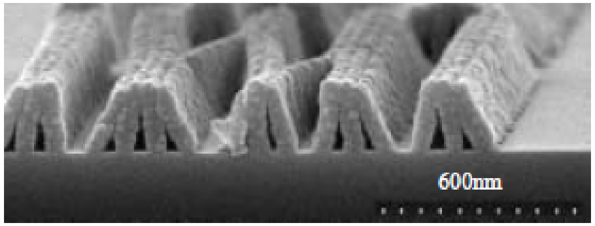
Neagtive Tone Resists with scCO2 Dry for Collapse Issue

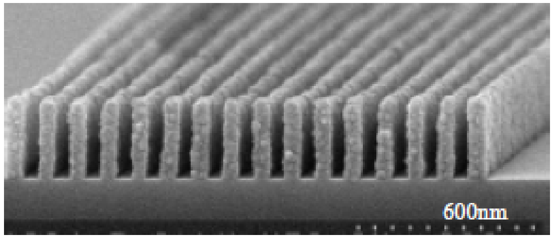
High mechanical strength / low capillary force are promising for collapse

Conventional dry **Supercritical dry**

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

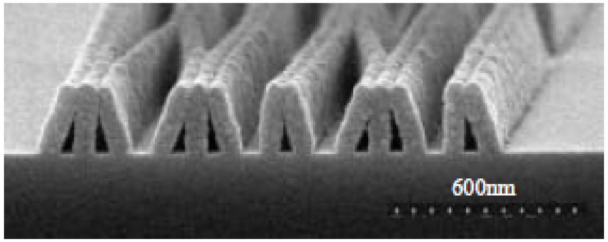
Tr = 250 nm

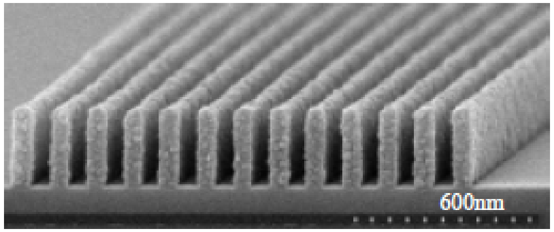




70nm 1:1 L/S Thickness:250nm(aspect ratio=3.6)

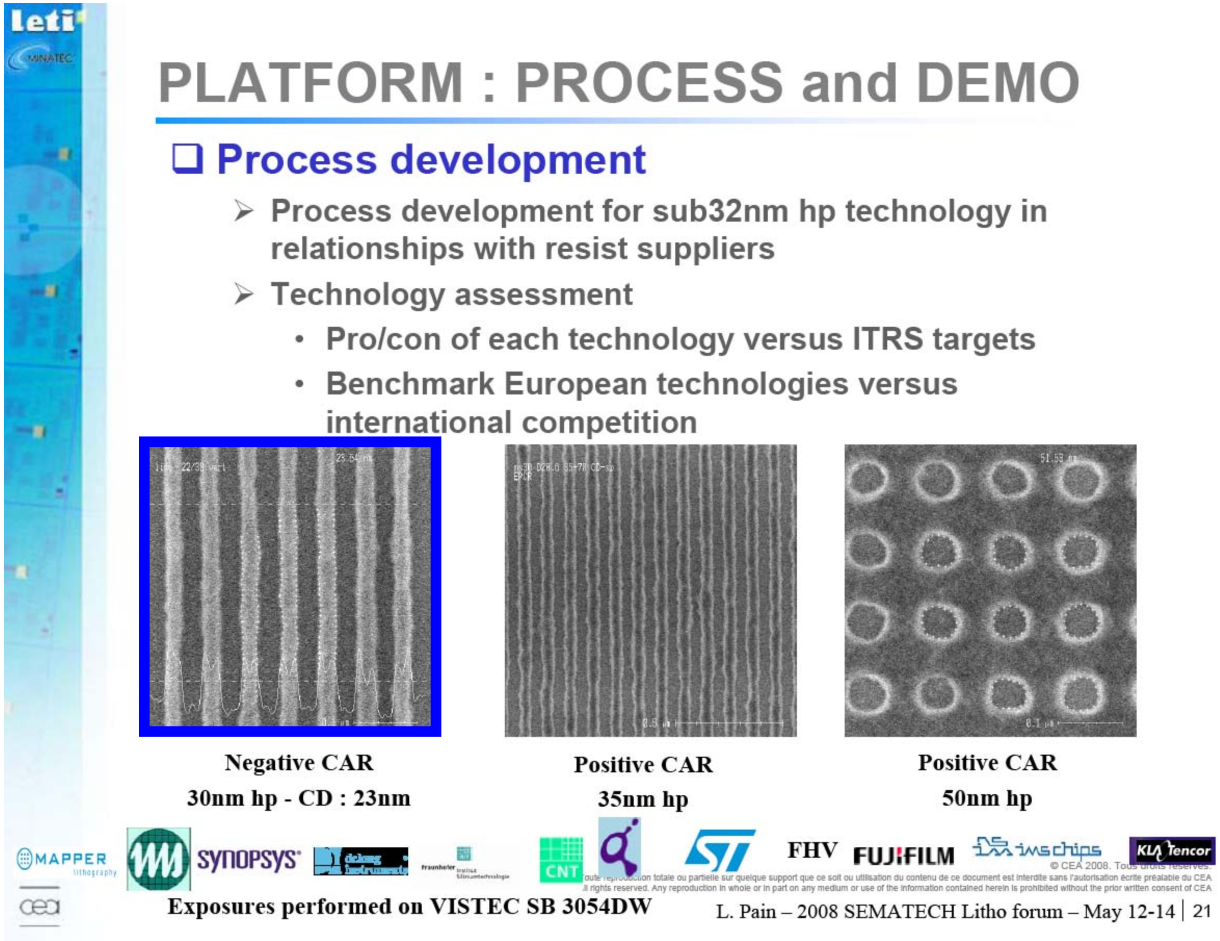
Tr = 250 nm





TMAH Development, X-linking type negative tone EB resist

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

Exposures performed on VISTEC SB 3054DW

L. Pain – 2008 SEMATECH Litho forum – May 12-14 | 21

Negative tone
Fujifilm EB resist

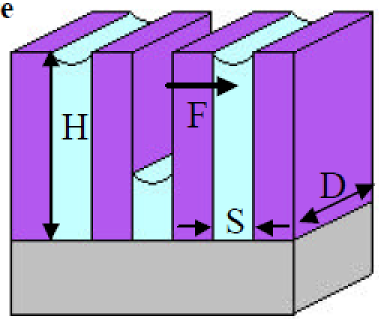
Similarities of EUV and EB promise the resolution below hp 30 nm on EUV

Comparison between EUV and ArFi resists

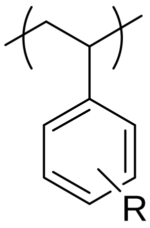
Capillary Pressure

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

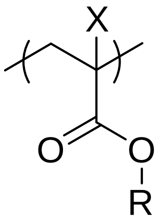
$$R = \frac{S}{2\cos\theta}$$



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



EUV resist



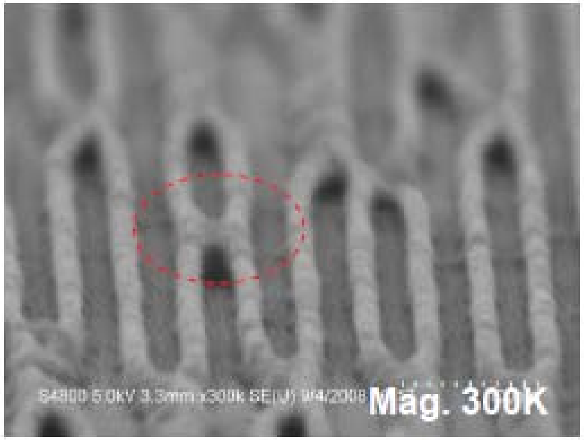
ArFi resist

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	*Not* enough ?	?
Optimal **ArFi** resist (Acrylic resin)	46 nm	3.0	1	*Not* enough ?	?
Negative tone resist (X-linking type) x scCO2 dry	60 nm	>> 4	~ 0	*Not* enough ?	High ?

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

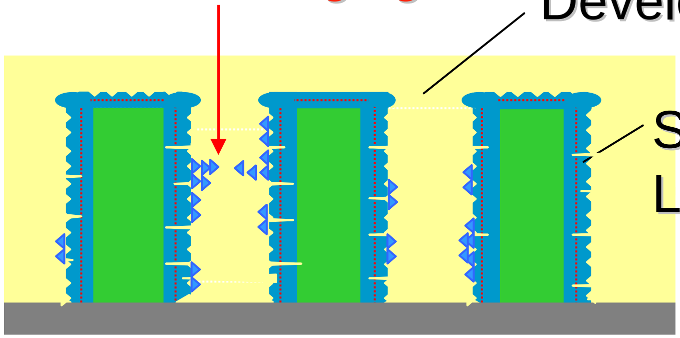
Microbridge Formation Dominated by Swelling in Development

22 nm hp patterns



Data courtesy of SEMATECH

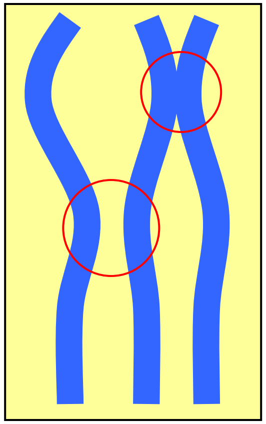
Positive tone EUV resist



Microbridging

Developer

Swelling Layer



Deformation of pattern might be occur by “swelling”

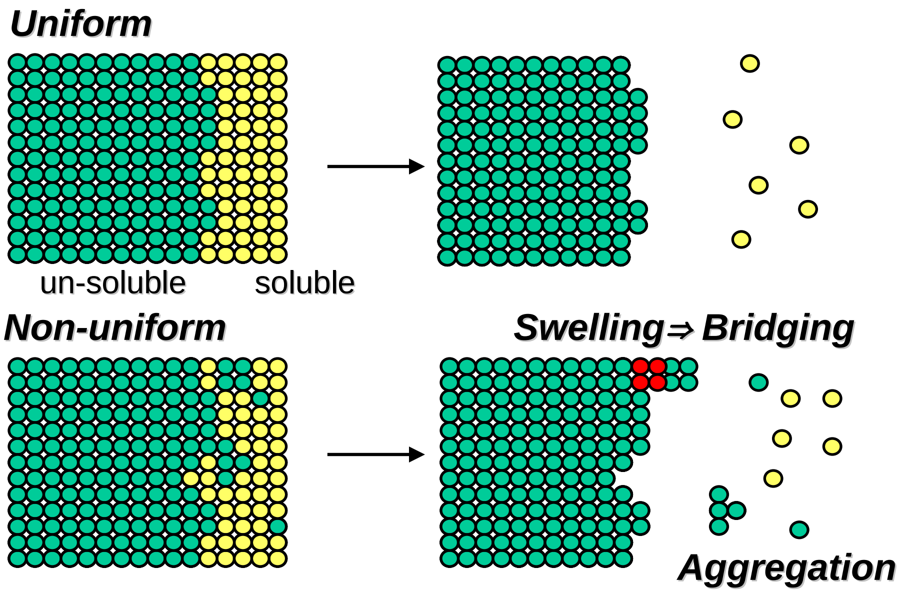
Design Principles for Low Swelling Resists

Design Principles

① Increasing rate of (ii) + (iii)

⇒ (i) < (ii) + (iii)

② Increasing uniformity in development



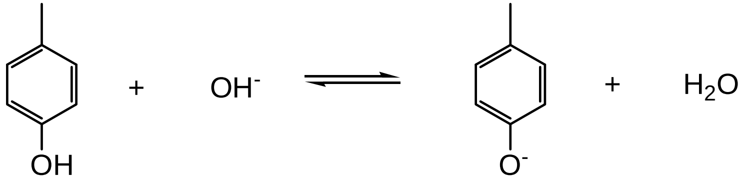
Development steps

(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

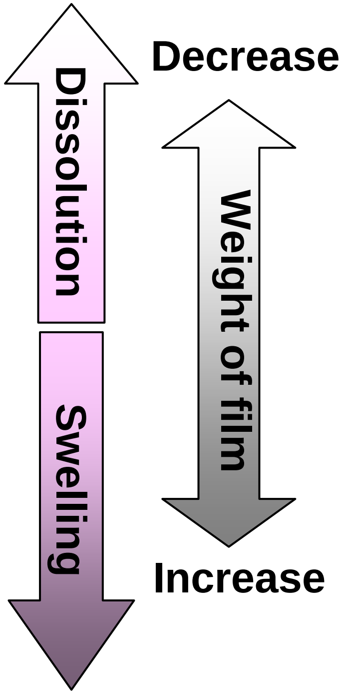
Low molecular weight polymer

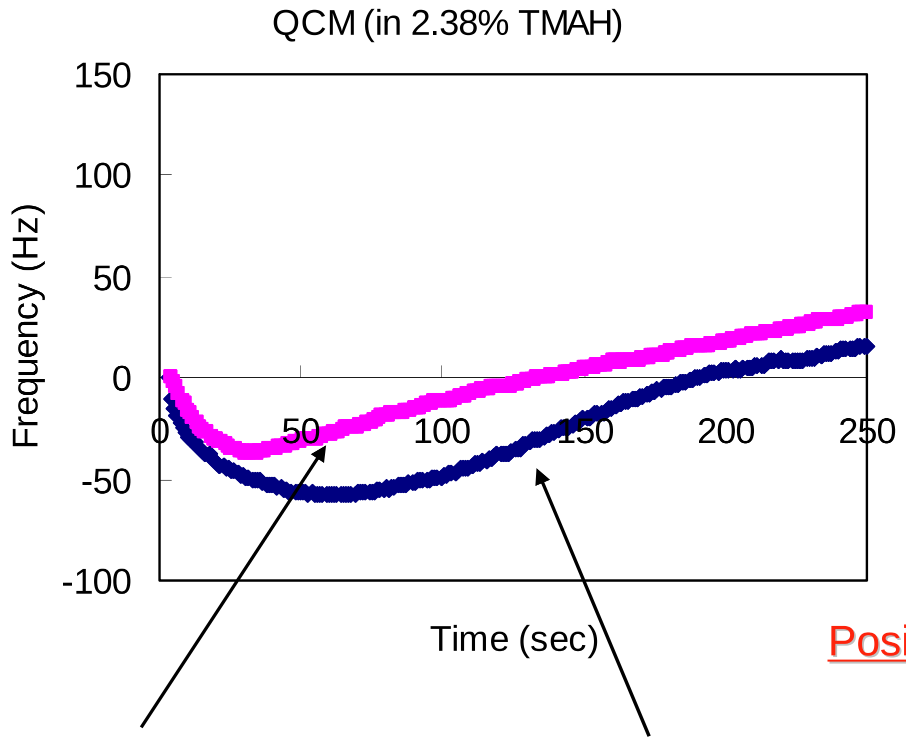
Weak intermolecular interaction polymer

(iv) Diffusion into solvent layer

Microbridge Suppression using a Polymer with Controlled Hydrophilicity

QCM Analysis



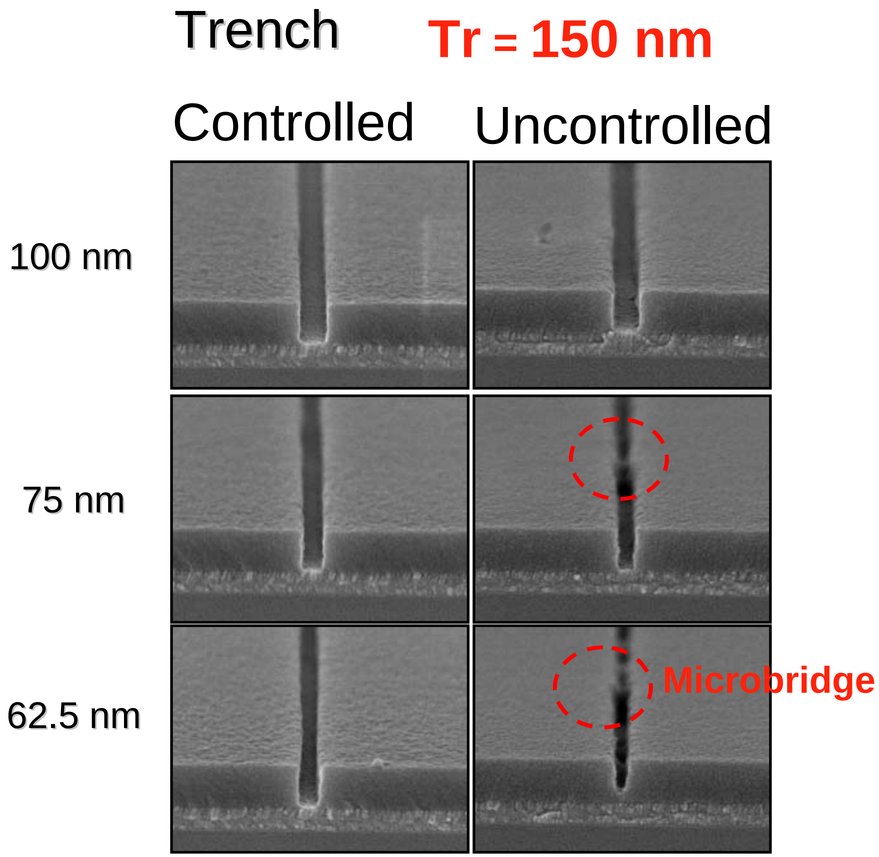


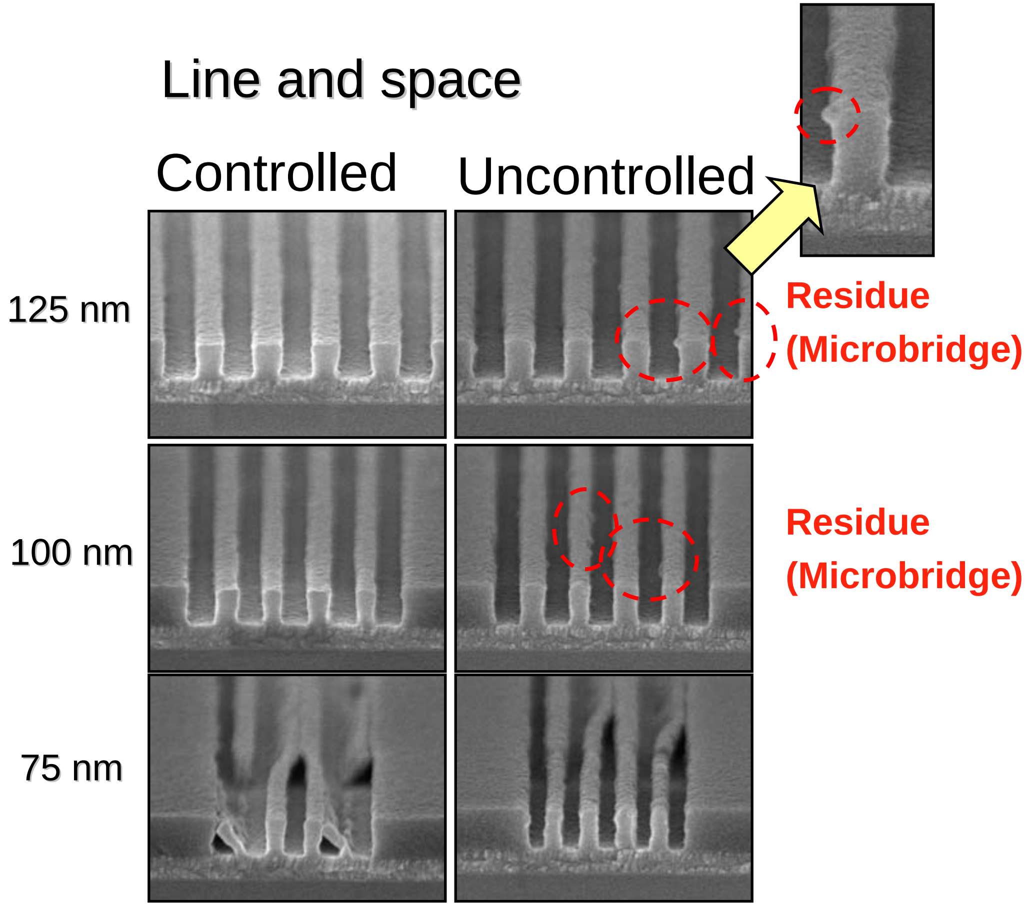
Positive tone EUV resists

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

Design Principles for Low Swelling Resists

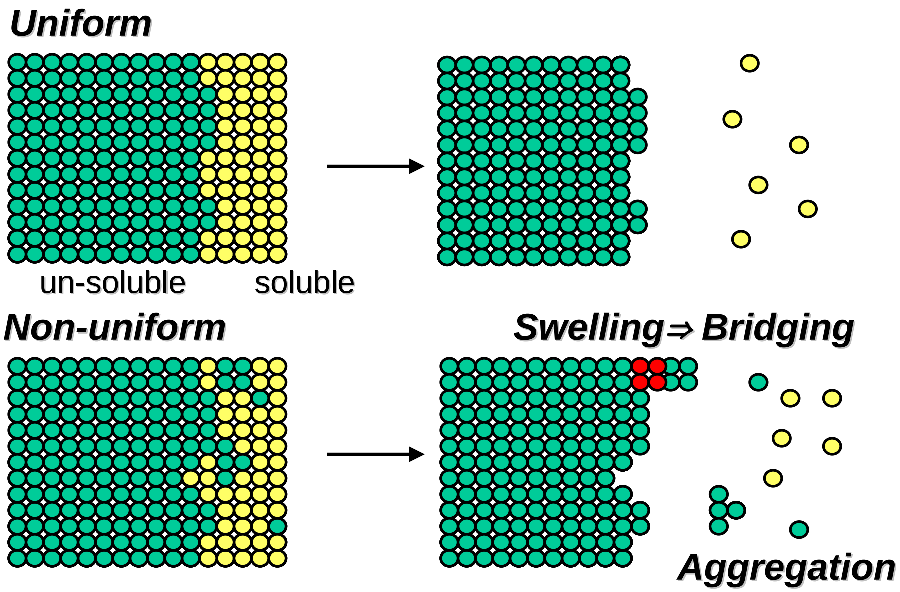
Design Principles

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)

Organic Developer !

(iii) Solvation of polymer

⇒ Hydrophilic polymer
Low molecular weight polymer
Weak intermolecular interaction polymer

(iv) Diffusion into solvent layer

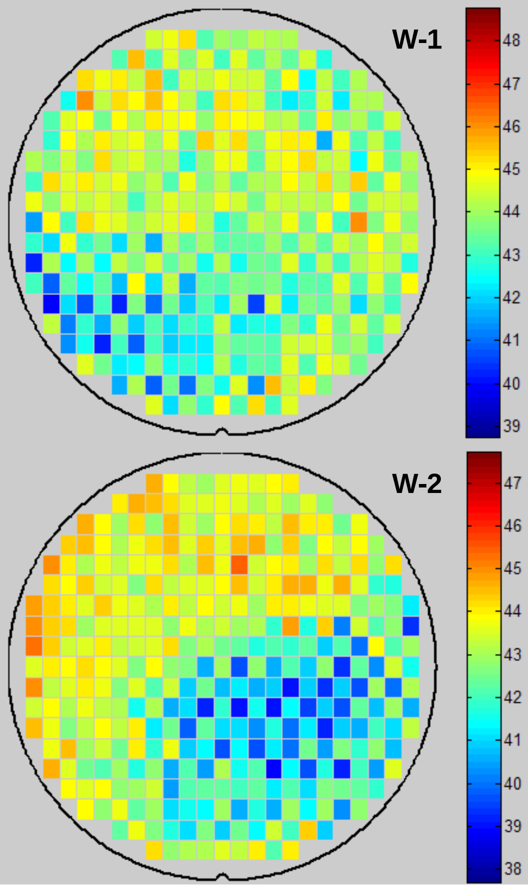
NTD is a Good Choice for Low Swelling

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

NTD
Developer: FN-DP001
Dynamic dev.-1

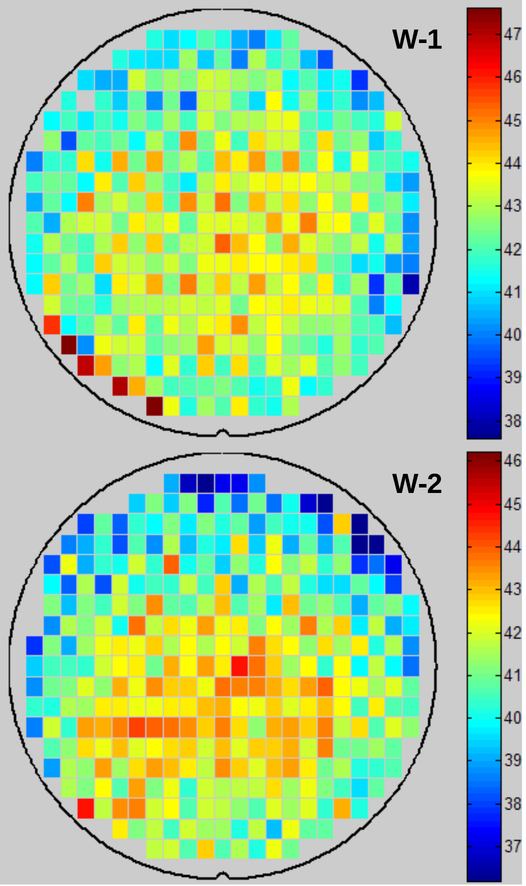
45nm trench
128nm pitch
NA1.2
dipole illumination

PTD
Developer: OPD5262
Dynamic dev.-2



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

NTD	**PTD**
Mean	
42.7 nm	41.2 nm
3 x STD dev.	
4.2 nm	5.1 nm



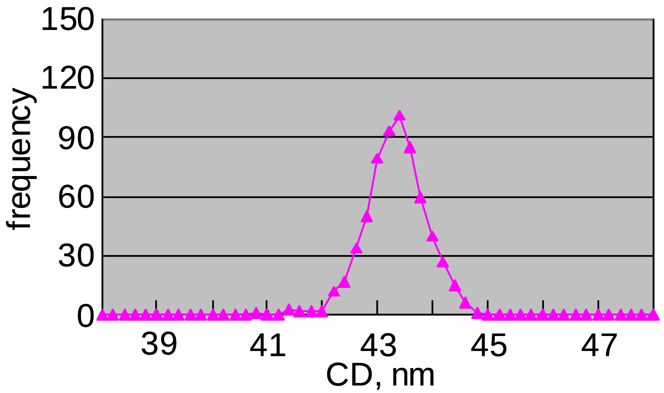
NTD is a Good Choice for Low Swelling

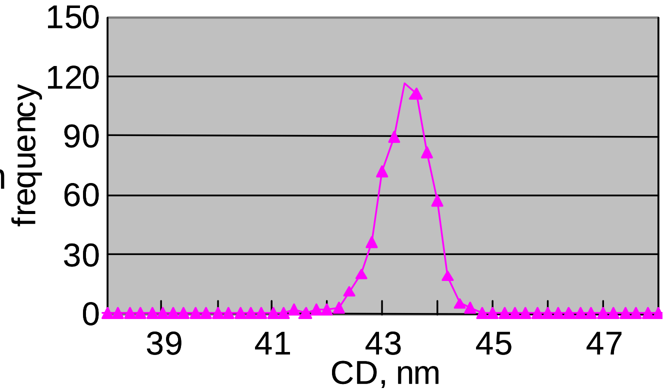
Tarutani et al., SPIE 2009, 7273-11.

NTD
Developer: FN-DP001
Dynamic dev-1.

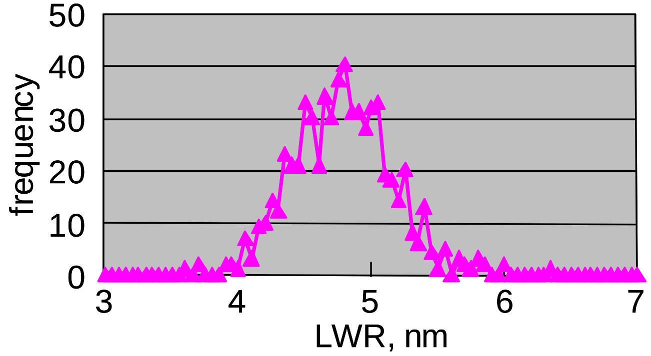
43 nm trench
90 nm pitch
NA1.35
dipole illumination

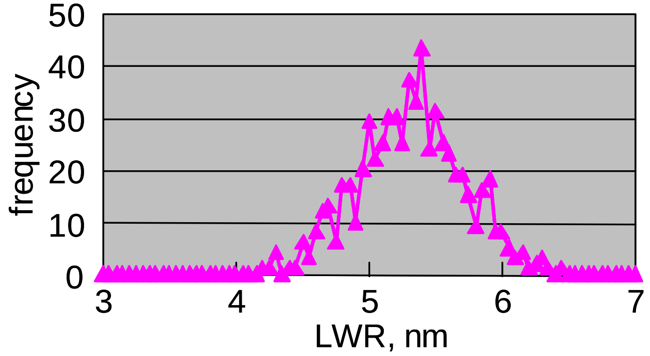
PTD
Developer: OPD262
Static dev.



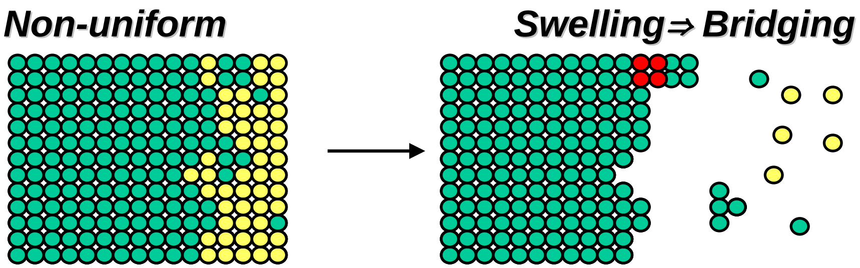


	NTD	**PTD**
Mean	43.2 nm	43.3 nm
3 x STD dev.	1.6 nm	1.4 nm
Mean	4.8 nm	5.3 nm
3 x STD dev.	1.1 nm	1.2 nm

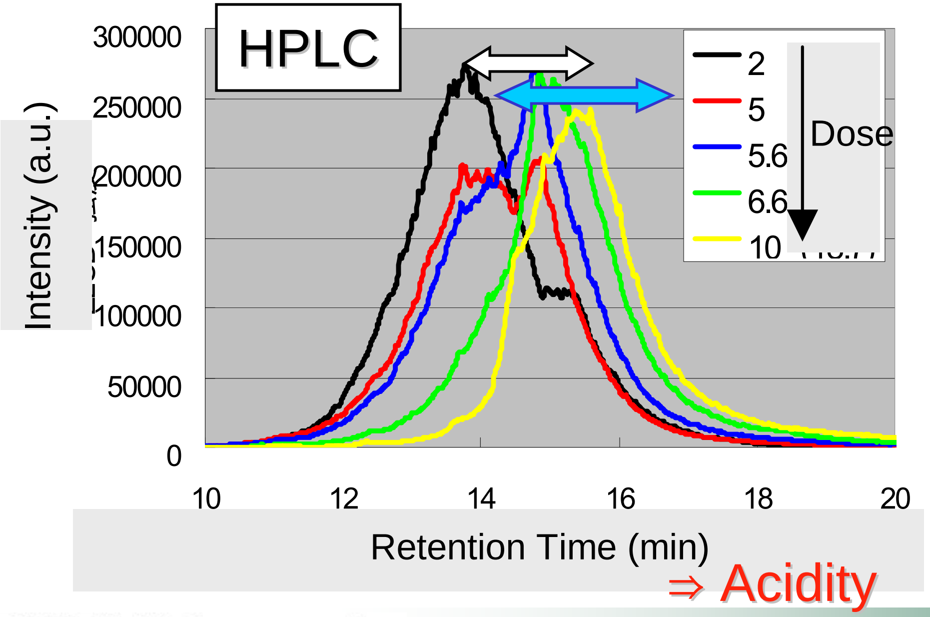


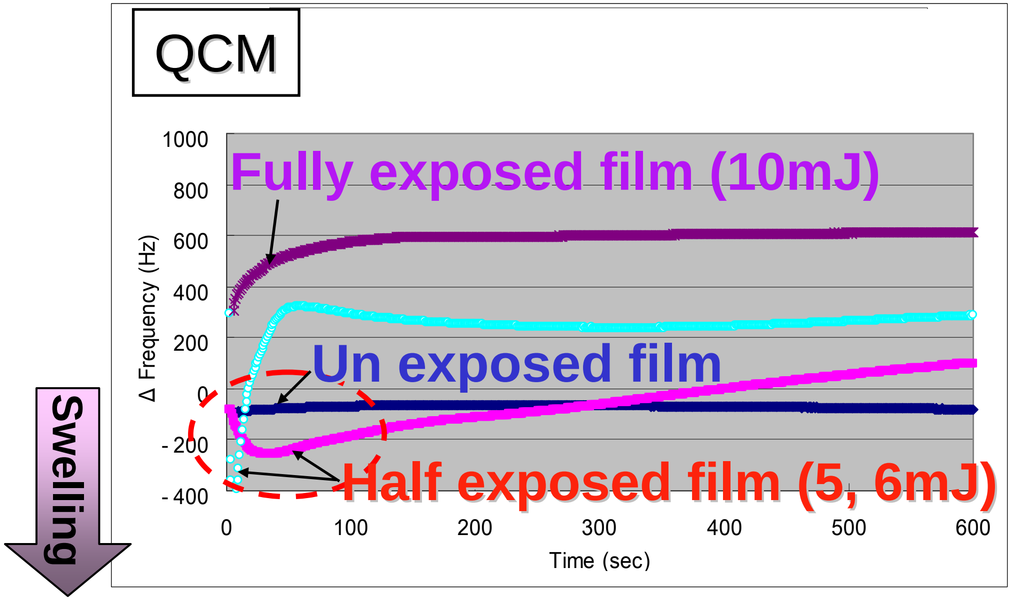


Non-uniform Deprotection also Causes Swelling



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 !