Pattern Collapse Mitigation Strategies for EUV Lithography

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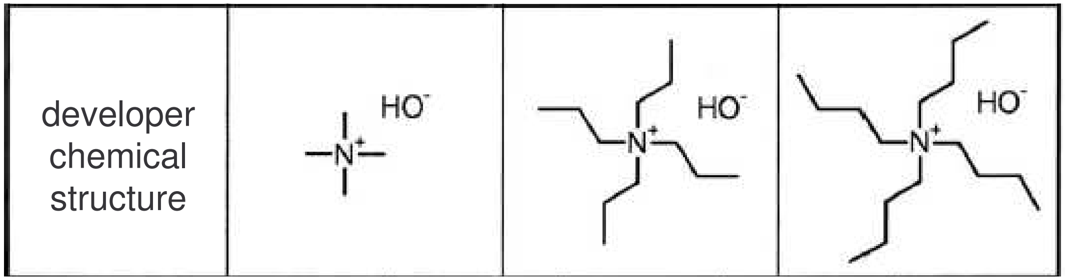
Outline

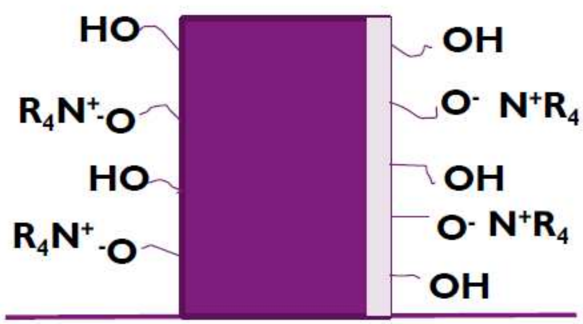
- Pattern Collapse Control for EUV Resists - Industry Status
- Reassessment of pattern collapse driving forces
- Surfactant-containing rinse & resist design for collapse mitigation
- Rinse solvent drying utilizing supercritical fluids
- Thin resist image transfer utilizing metal-based hardmask vs SiARC

Pattern Collapse Control for EUV Resists – Industry Status

- Increased pattern collapse margin with TBAH developer - surfactant rinse combination
- Increase in resist sidewall hydrophobicity with TBAH rinse

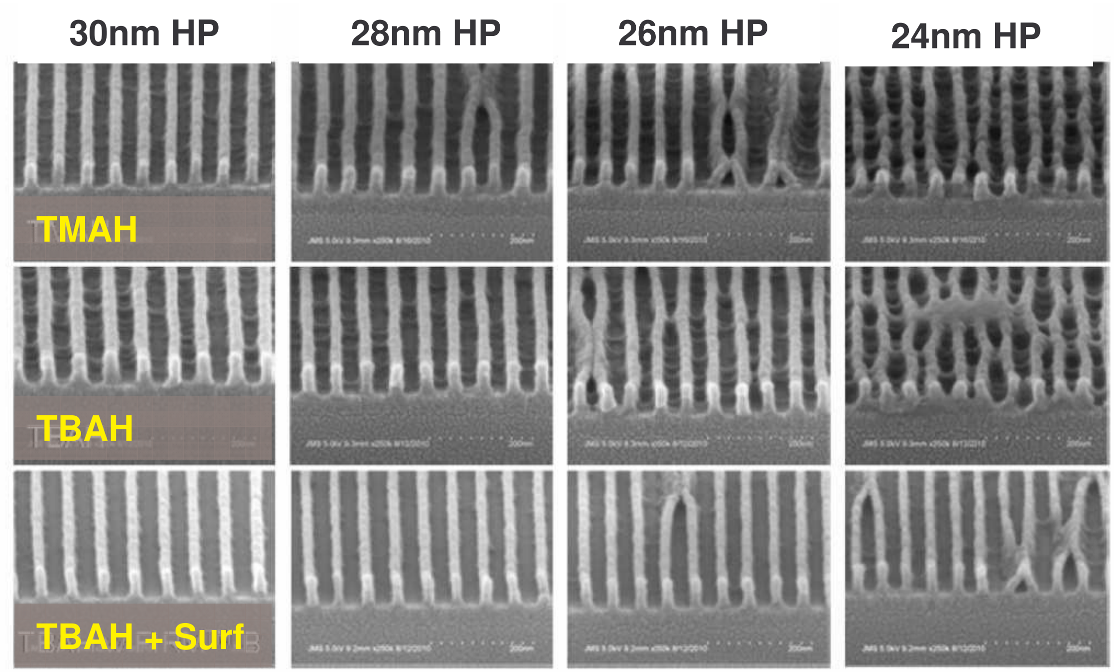


T. Itani et al. JVSTB 27(6) 2986 (2009) - SELETE



R.Gronheid et al. - IMEC

EUVL Symposium – Kobe, Japan (2010)

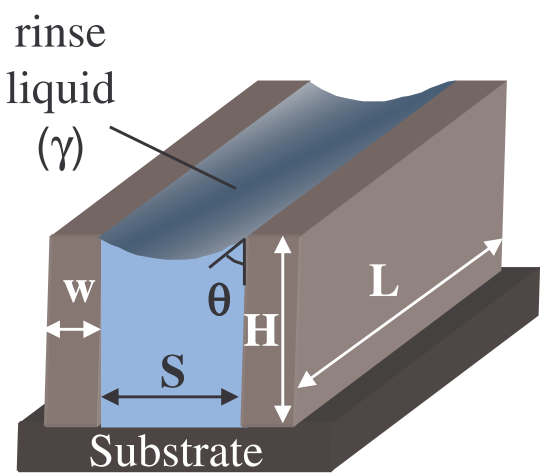


EUV resist patterned on EUV eMET tool - SEMATECH

K.Petrillo et al. Proc. of SPIE, Vol. 7969, 796913 (2011)

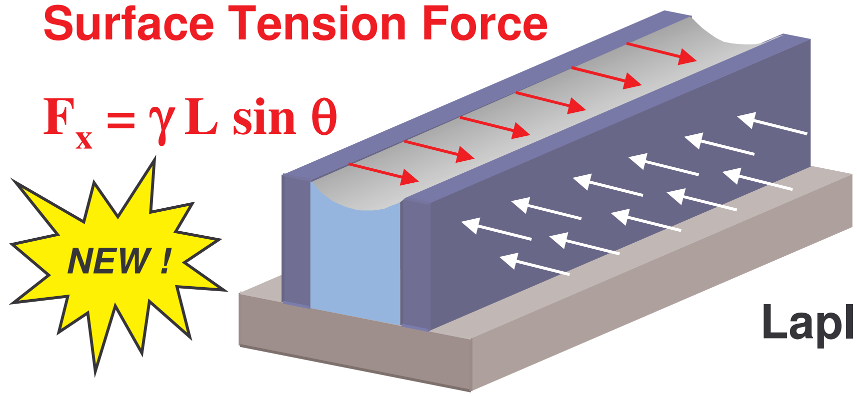
Challenging Our Knowledge on Pattern Collapse

- *"Understanding Pattern Collapse in Photolithography Process Due to Capillary Forces"*, S. Farshid Chini and A. Amirfazli (Dept. of Mechanical Engineering, University of Alberta, Canada) - Langmuir 2010, 26(16), 13707–13714



Surface Tension Force

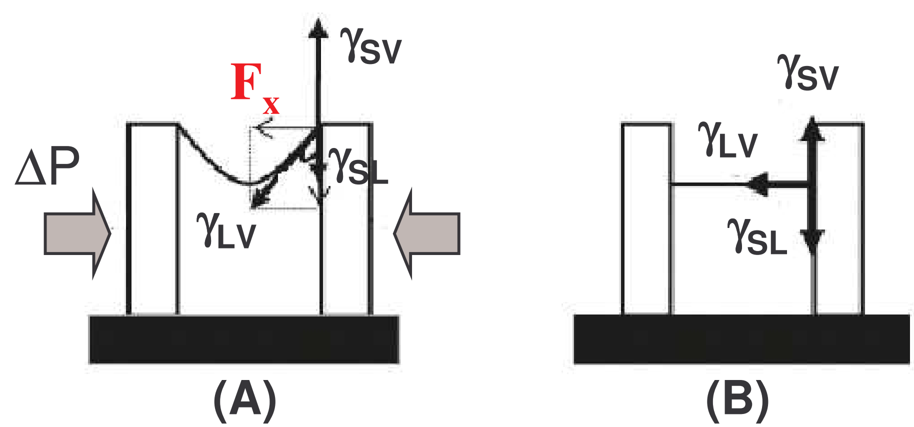
$$F_x = \gamma L \sin\theta$$



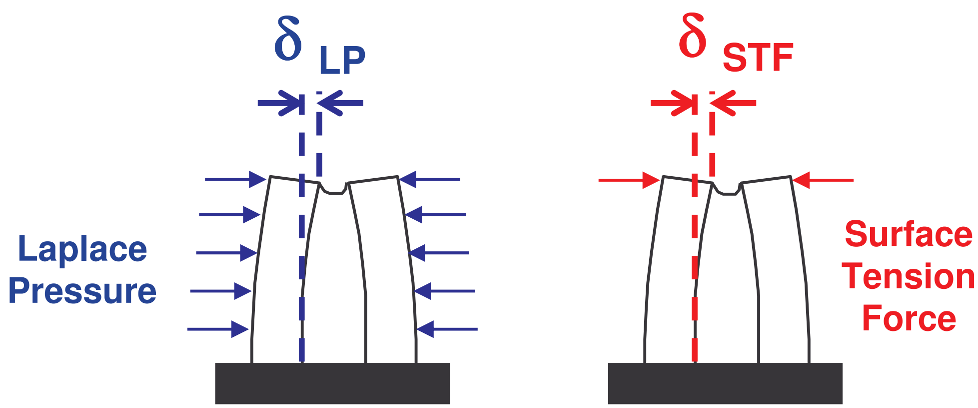
Laplace Pressure

$$\Delta P = (2\gamma\cos\theta)/S$$

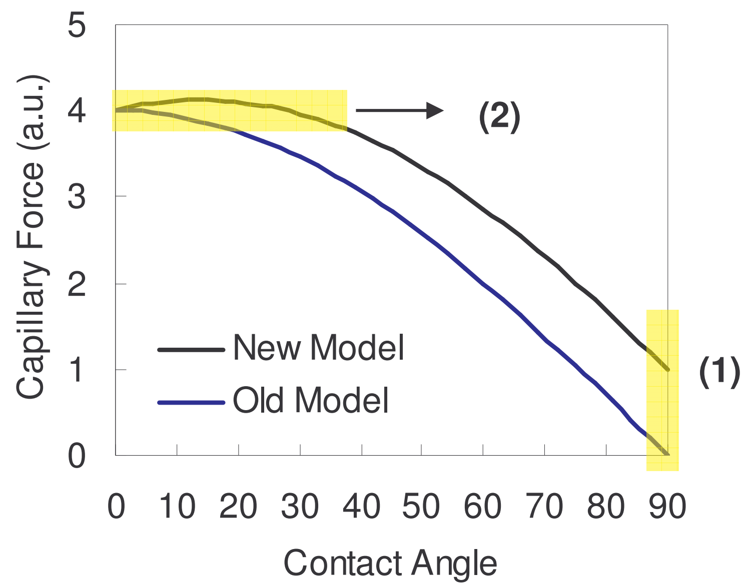
- **Laplace Pressure:** applied to the entire pattern sidewall
- **Surface Tension Force:** applied to the resist-air-liquid contact line



Challenging Our Knowledge on Pattern Collapse



Note: commercial surfactanated rinses typically display $\theta = 0$



Assume equal Line/Space (S = w) and

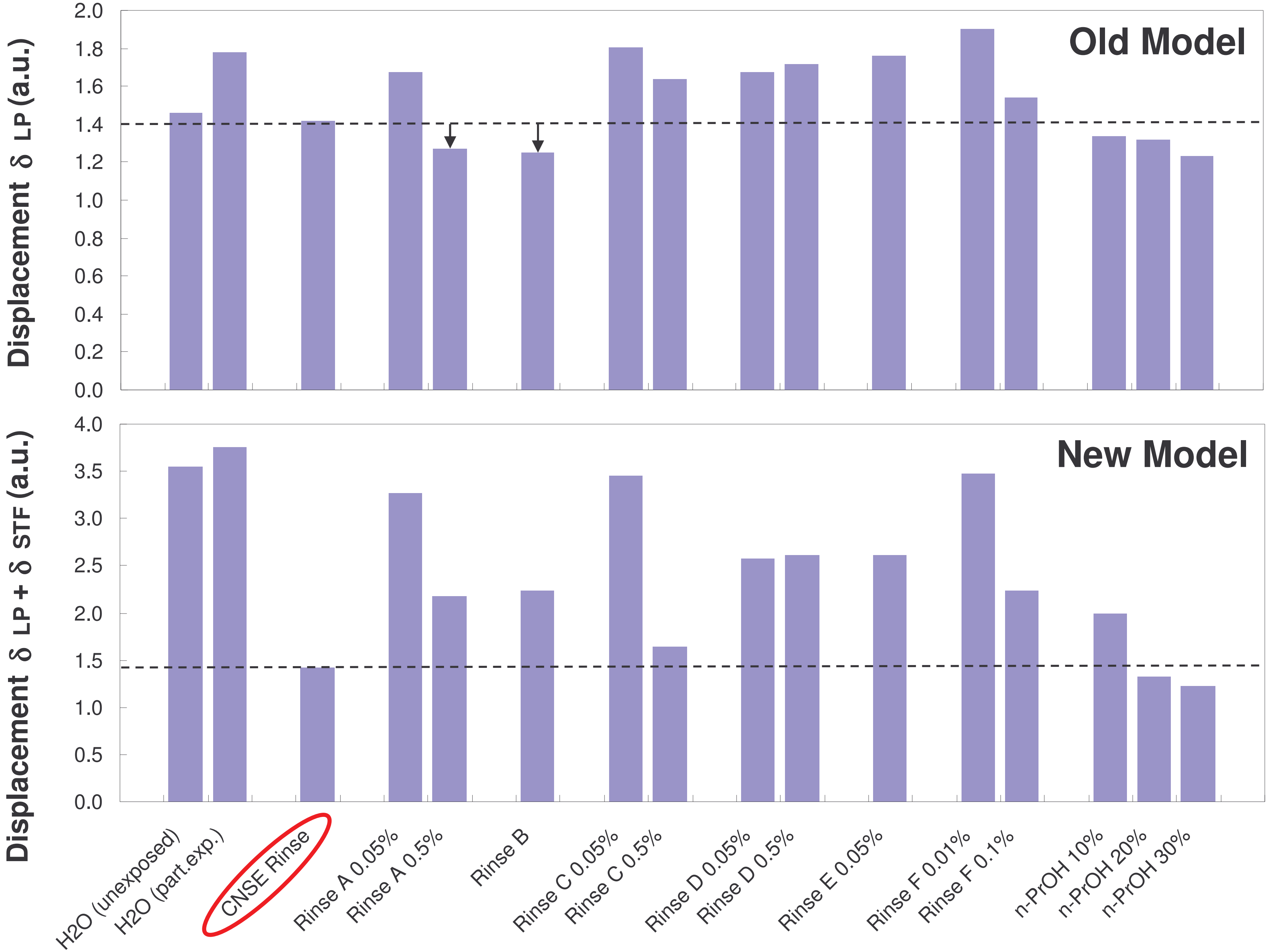
Aspect Ratio, AR = H / w ~ 2

$$\delta_{LP} / \delta_{STF} = \frac{1.5 \cos\theta}{\sin\theta}$$

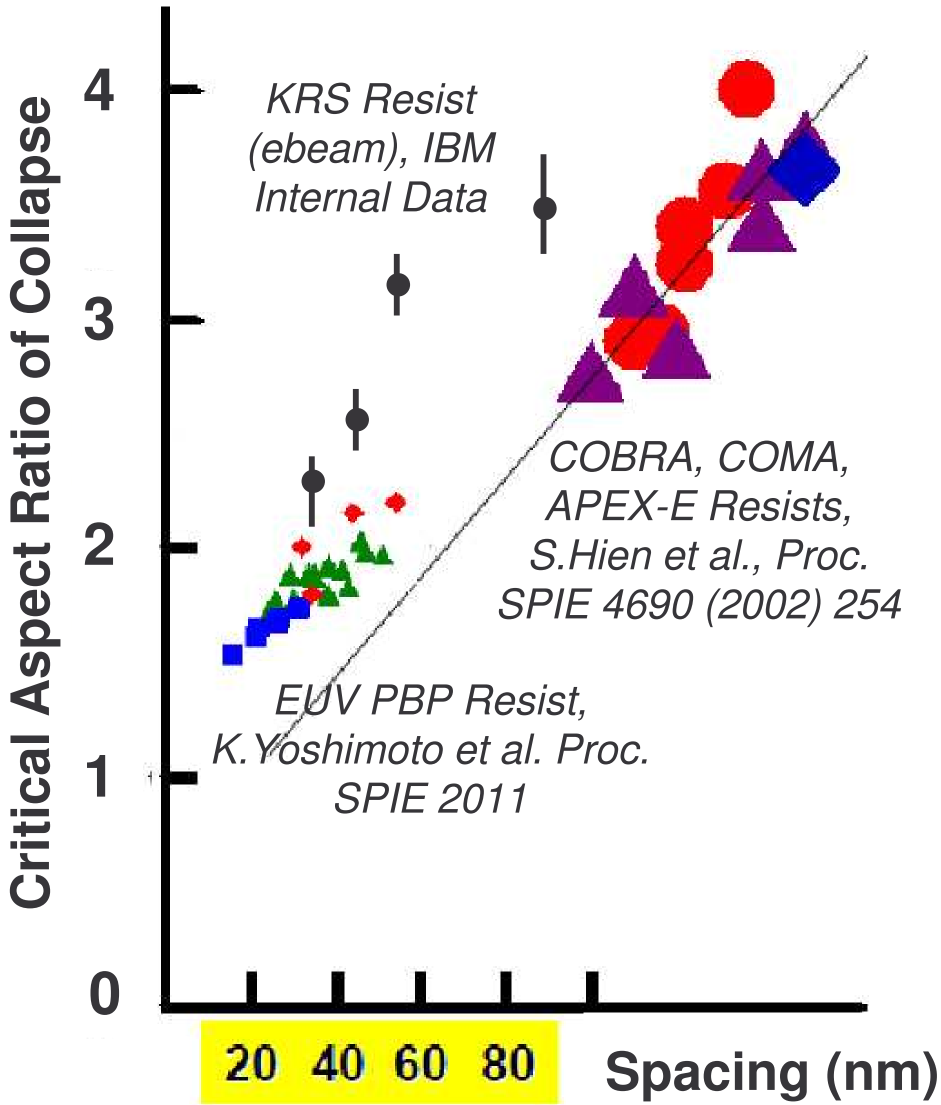
Information from new model

(1) Non-zero capillary force is present at $\theta = 90°$

(2) Negligible capillary force dependency on contact angle between ~ 0° - 40°


Old Model
New Model
Displacement δ LP (a.u.)
Displacement δ LP + δ STF (a.u.)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
H2O (unexposed)
H2O (part.exp.)
CNSE Rinse
Rinse A 0.05%
Rinse A 0.5%
Rinse B
Rinse C 0.05%
Rinse C 0.5%
Rinse D 0.05%
Rinse D 0.5%
Rinse E 0.05%
Rinse F 0.01%
Rinse F 0.1%
n-PrOH 10%
n-PrOH 20%
n-PrOH 30%

Can We Find Further Support for the New Model ?



Ref: K.Yoshimoto, Proc. of SPIE 2011 Vol. 7972, 79720K

- Old Model predicts negligible capillary force near θ = 90°
- CARC (EUV PBP resist) = 1.9 (old model)
- CARC (KRS, 30nm L/S) = 3.6 (old model)
- CARC (KRS, 30nm L/S) = 2.2 (exp. data)
- Old model overestimates CARC at high θ

resist	θ	resist	θ
EUV PBP	59.0 °	193 pos C	69.3 °
193 pos A	64.6 °	Ebeam neg	75.1 °
Ebeam pos	65.6 °	248 pos	81.7 °
193 pos B	67.3 °	157 pos	85.0 °
		KRS	**85.1 °**

PBP: polymer-bound PAG

CARC: Critical Aspect Ratio of Collapse

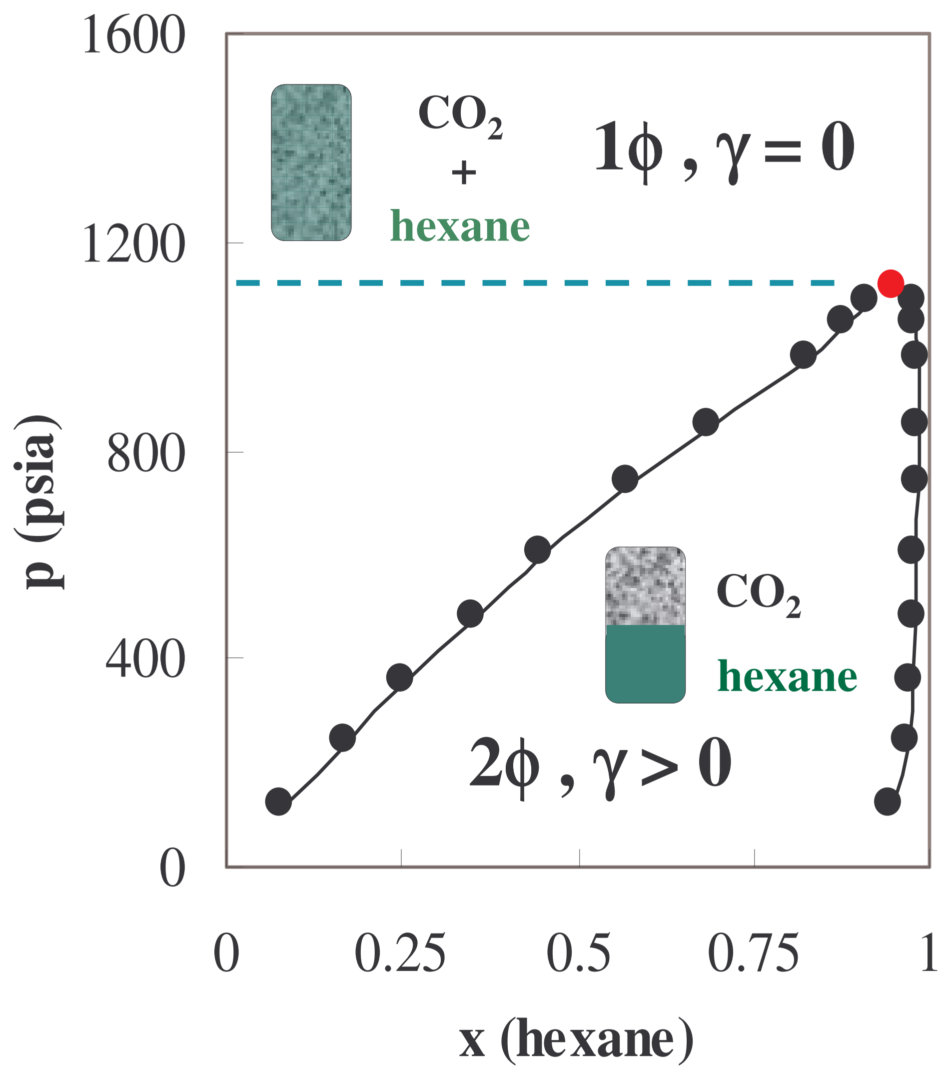
Rinse Solvent Drying Utilizing Supercritical Fluids

Supercritical drying pros & cons

- Ultimate γ reduction method
- No commercial tools for 300mm wafers
- Requires use of additional solvents
- Throughput can be impacted

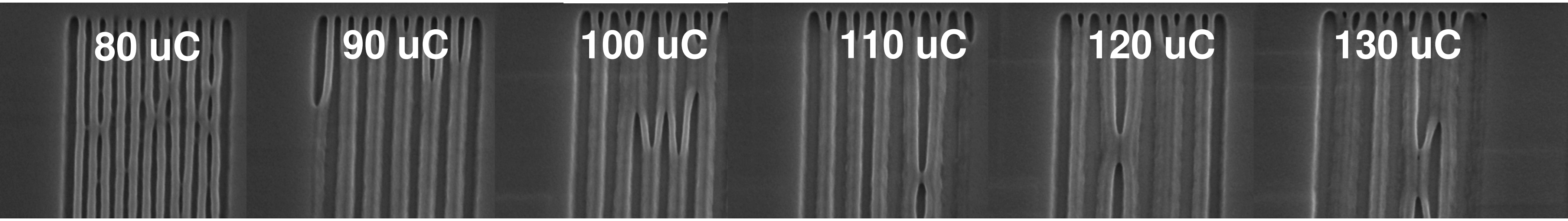
Supercritical drying conditions

- P = 1300 psi, T = 40C
- Rinse = hexane (70 mL)
- Dry = CO2 (300 mL)
- Flow Rate = 20 mL/min

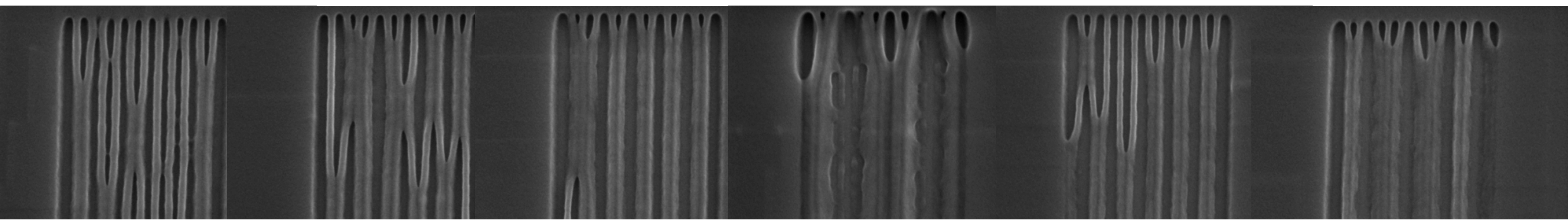


D.Goldfarb et al. JVSTB, Vol. 18 (6) 3313 (2000)

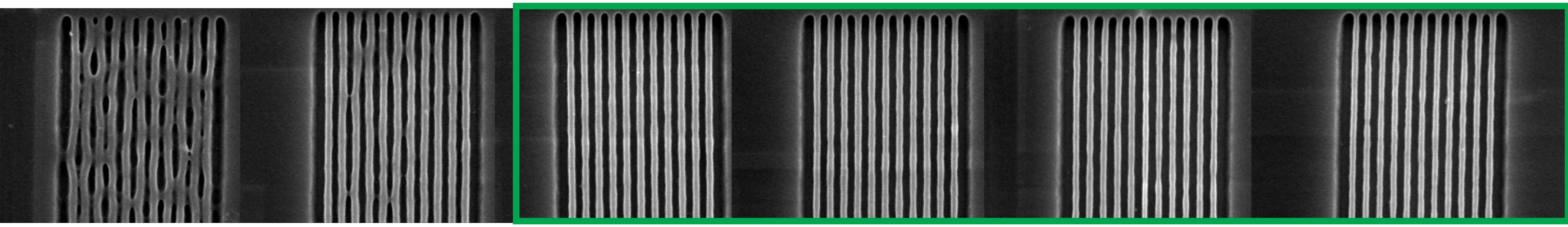
EUV Resist (ebeam exposure) - 25nm L/S, Aspect Ratio = 2.25



DI H2O Rinse (γ = 72 mN/m, θ = 59°)

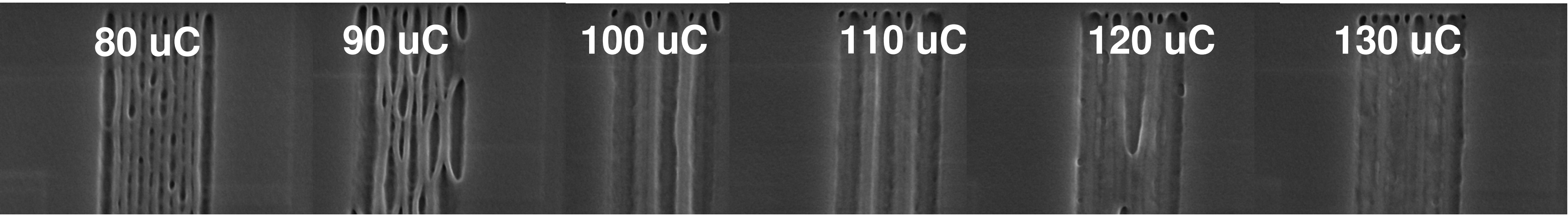


Surfactanated Rinse (γ = 39 mN/m, θ = 47°)

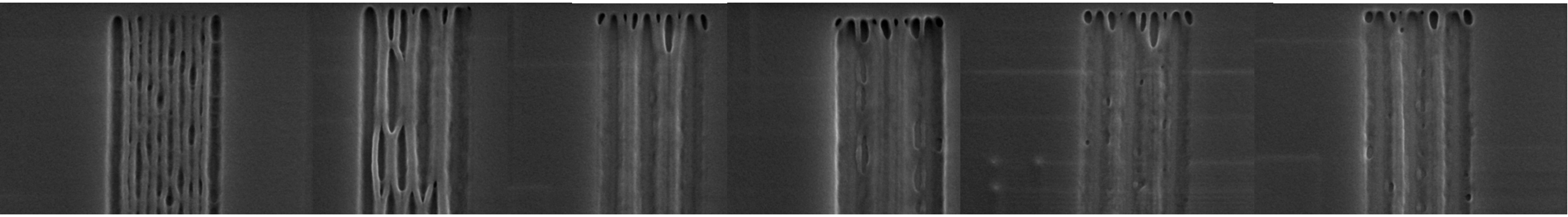


Supercritical CO2 Drying (γ ~ 0 mN/m)

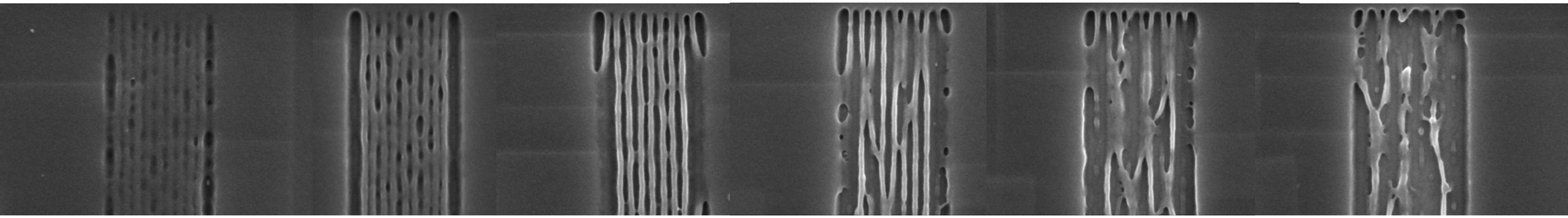
EUV Resist (ebeam exposure) - 20nm L/S, Aspect Ratio = 2.8



DI H2O Rinse (γ = 72 mN/m, θ = 59°)



Surfactanated Rinse (γ = 39 mN/m, θ = 47°)



Supercritical CO2 Drying (γ ~ 0 mN/m)

Thin EUV Resist Image Transfer (Ebeam Patterning)

- Attempt to transfer thin resist (32-35 nm thick, post EBL) into multilayer stack: spin-on SiARC (20nm thick) / organic underlayer (65nm thick) results in high LWR

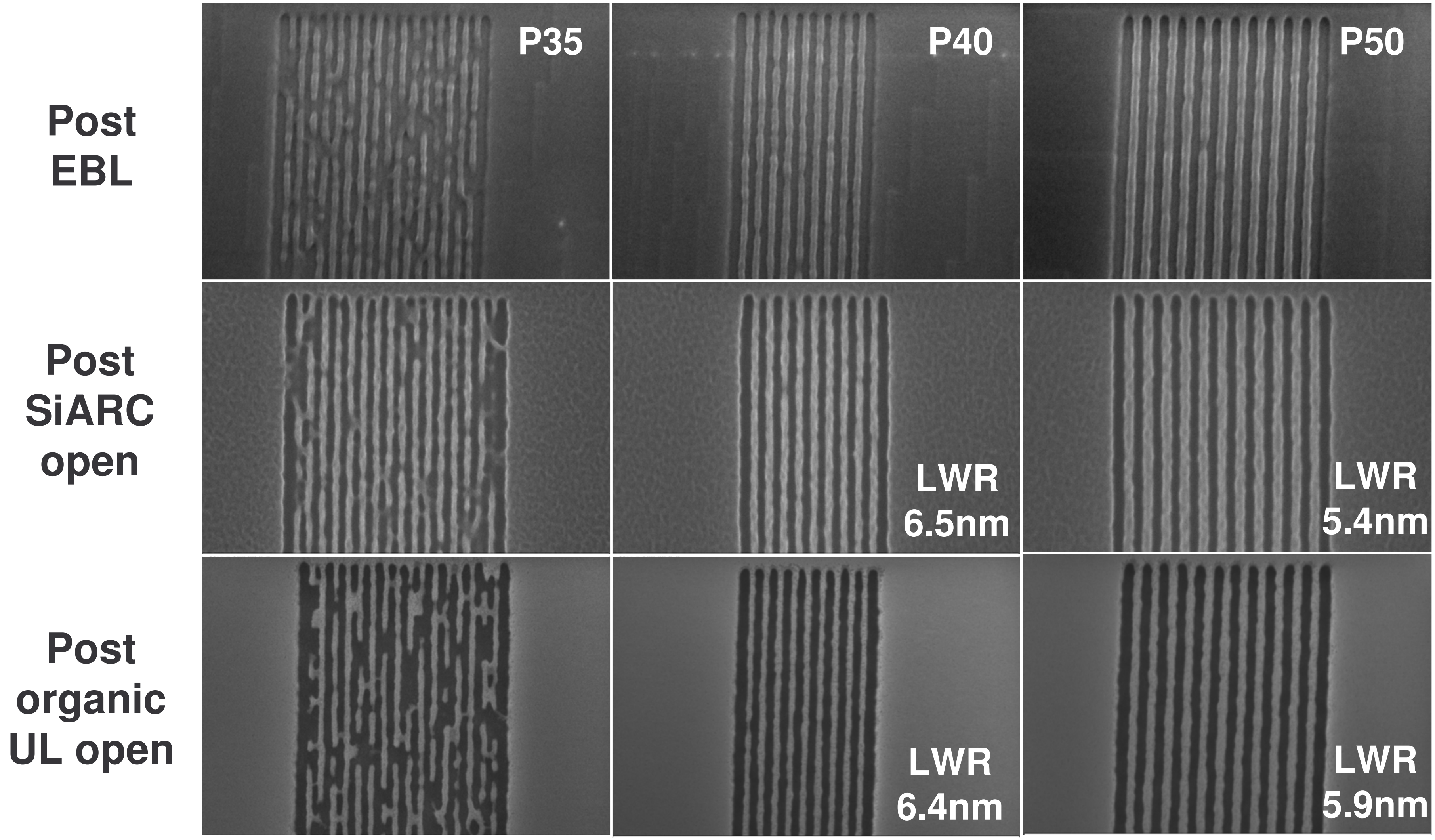
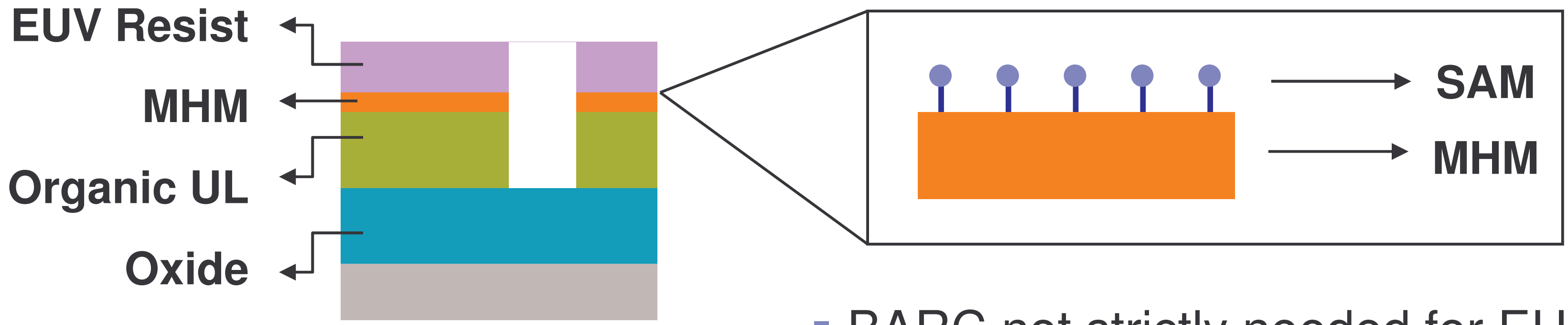


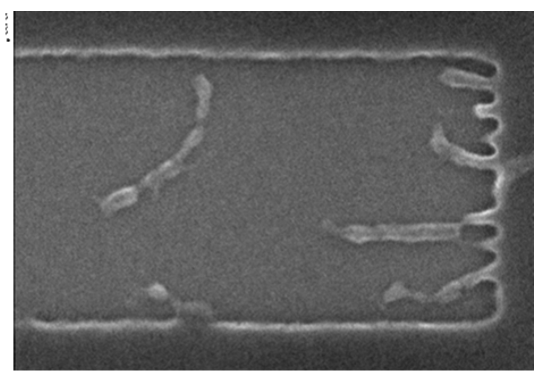
Image Transfer Using Metal-Containing Hardmask (MHM)

- Use highly etch resistant ultrathin MHM to enable more robust low-aspect-ratio resist image transfer into multilayer stack

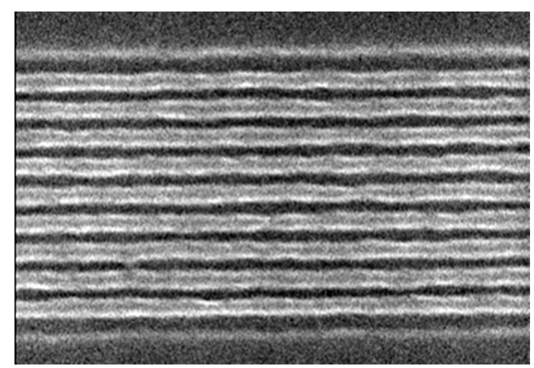


- BARC not strictly needed for EUV

- MHM (5nm thick)
  - Oxide, nitride
  - CVD, ALD, PVD
- Self-assembled monolayer (SAM) used to promote resist adhesion to MHM



EUV resist on bare MHM

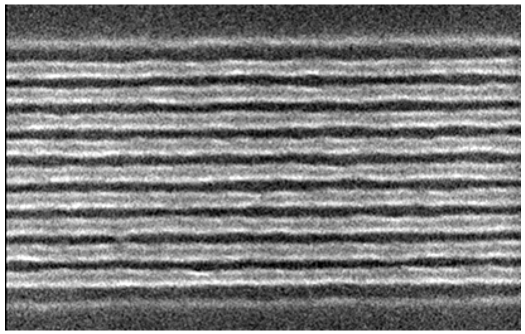


EUV resist on MHM-SAM
20nm L/S, ebeam patterning

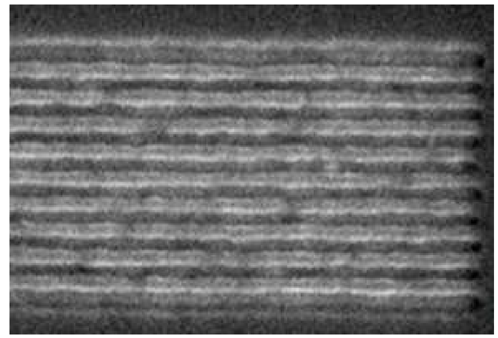
EUV Resist Patterning on MHM Substrate (20nm L/S, EBL)

- Pattern quality on MHM substrate comparable to SiARC from top down images

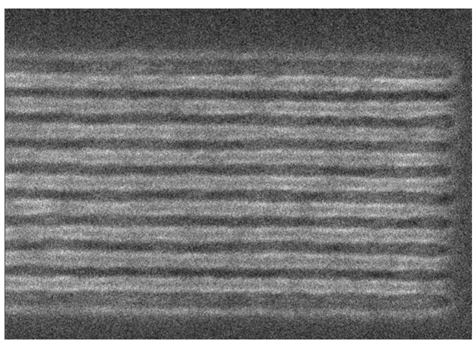
Resist on MHM1 / SAM, 110 uC
DUV Track



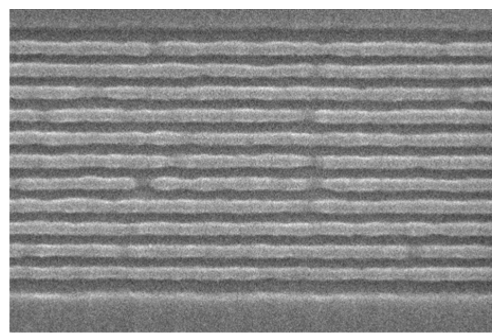
Resist on MHM2 / SAM, 90 uC
DUV Track



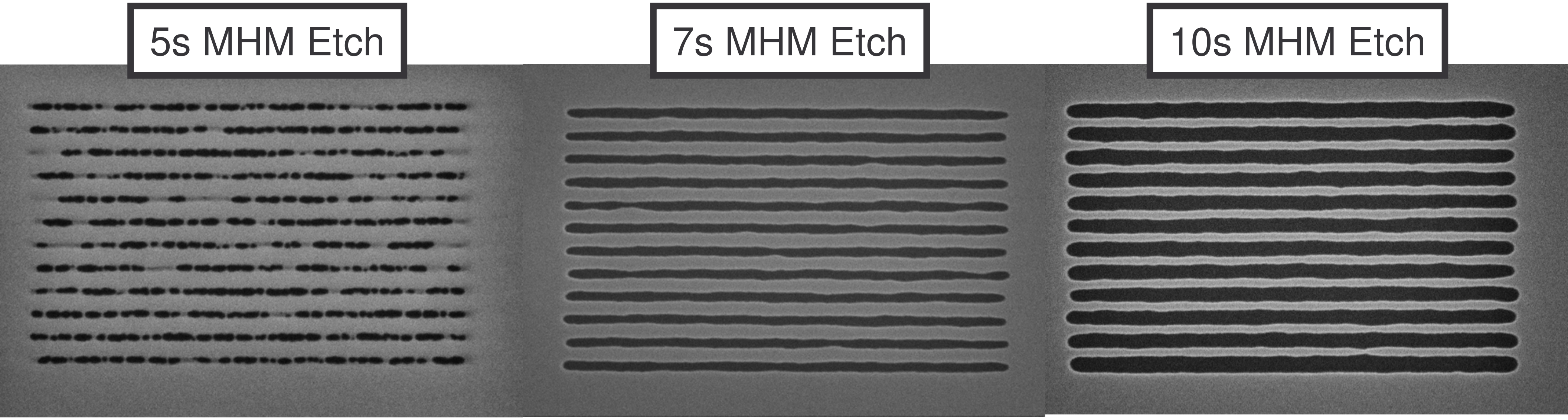
Resist on MHM3 / SAM, 90 uC
DUV Track



Resist on SiARC, 90 uC
DUV Track



EUV Resist on 5nm MHM/Organic UL/Ox Post-Organic UL Open



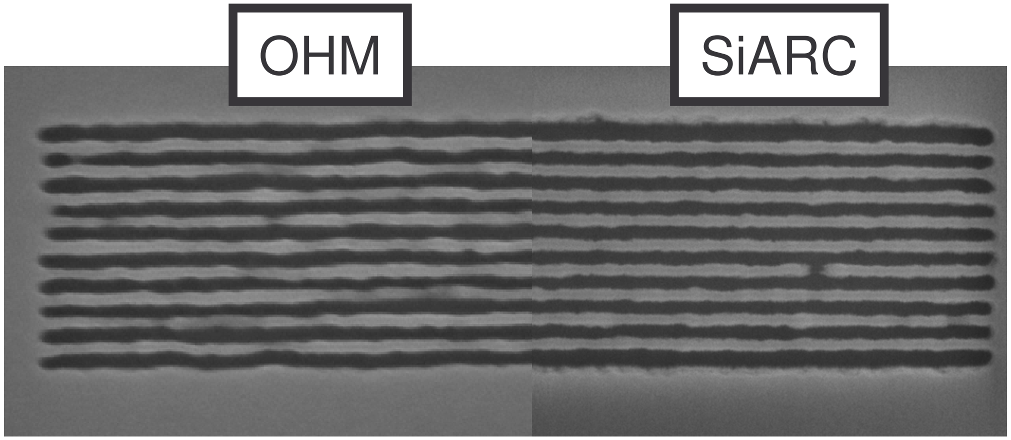
P50

LER = 3.1 ± 0.10nm
LWR = 4.8 ± 0.19nm

- Resist (32-35 nm thick post EBL) consumed in ~ 15 - 20 sec during RIE
- Timed etch needs to be tuned
- MHM removal needs to be worked out

Oxide HM vs SiARC vs MHM Schemes – Post Organic UL Open

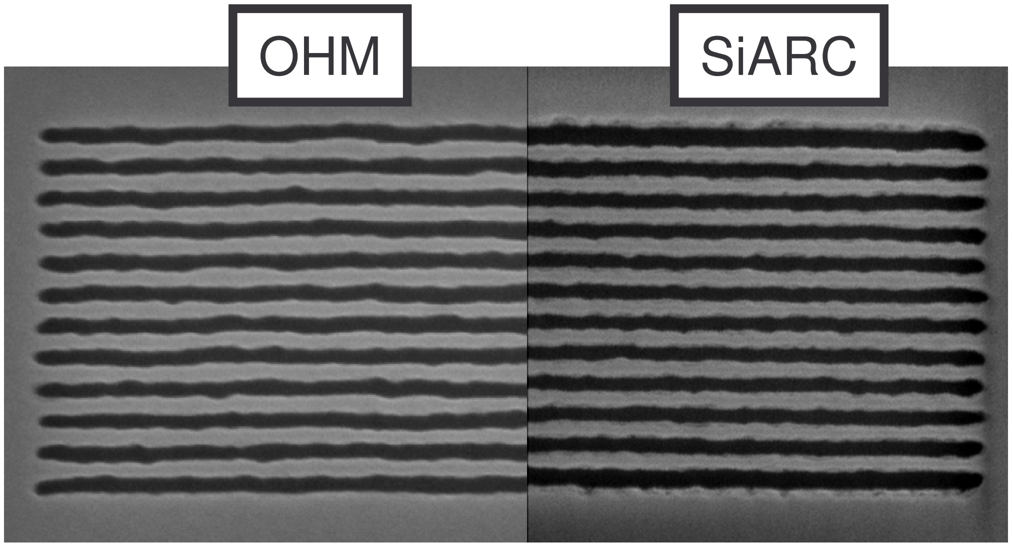
P40



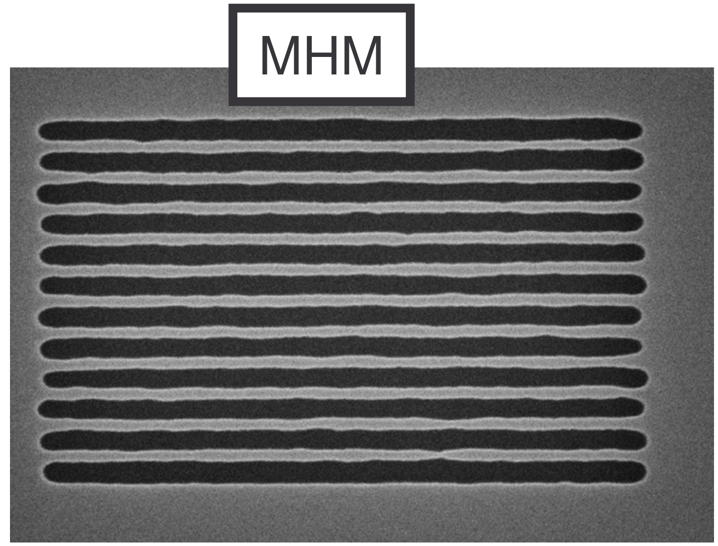
MHM

our next step

P50

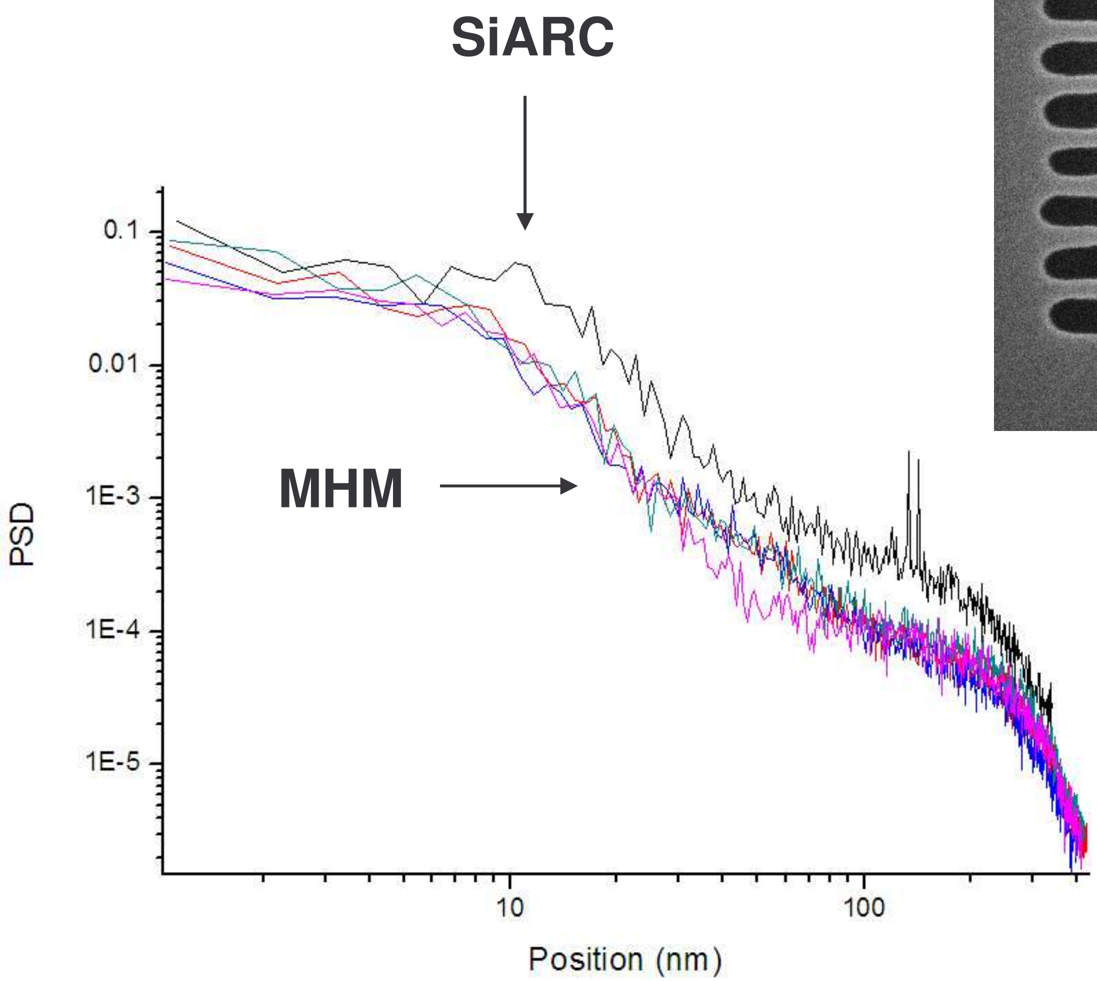


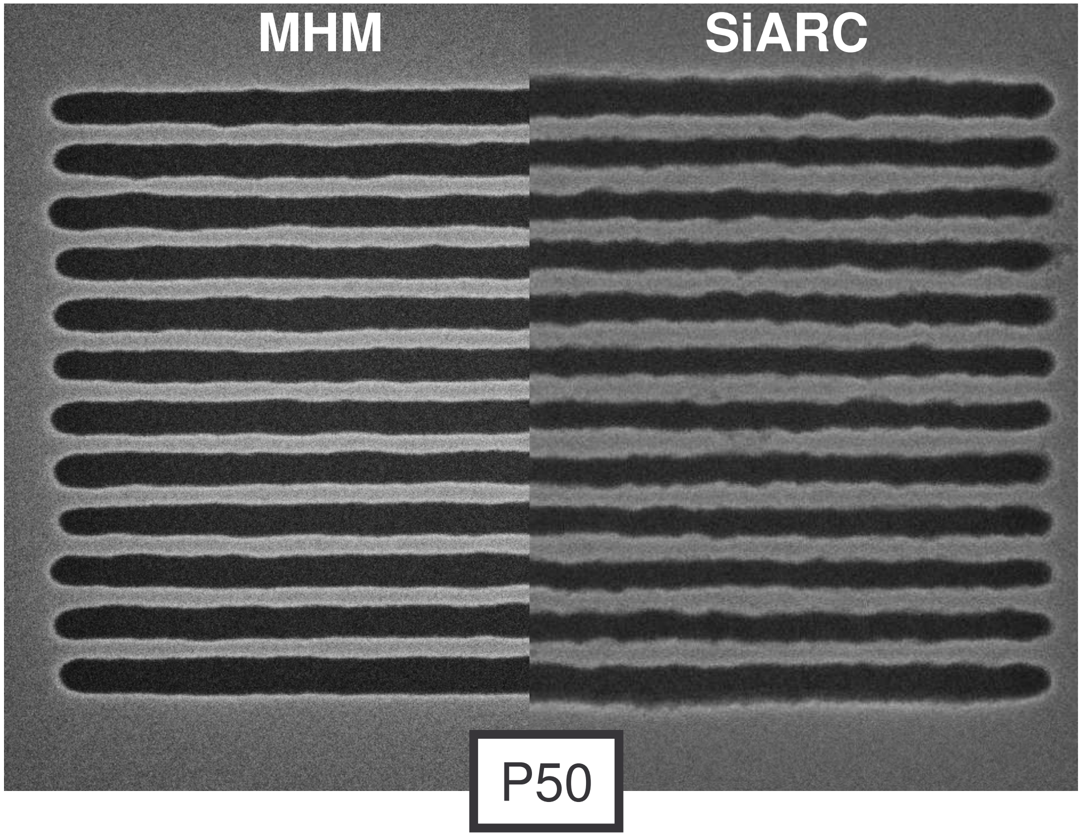
LWR = 5.4 nm



LWR = 4.8 nm

PSD Comparison





- High frequency LWR removal by use of 5nm MHM in place of 20nm SiARC

Conclusions

- New improved capillary force model better describes interaction between rinse and resist pattern sidewall compared to presently used model
- Surfactant-containing rinse selection and high-contact-angle resist performance better justified by new model
- Supercritical CO_2 drying of positive tone chemically amplified EUV resist (polymer bound PAG-based) effective up to aspect ratio = 2.25 at 25 nm L/S
- Thin EUV resist image transfer into multilayer stack (SiARC/UL) results in high LWR after organic underlayer RIE open
- Use of highly etch resistant ultrathin metal-based hardmask in place of SiARC enables image transfer with reduced LWR.

Acknowledgments

- Karen Petrillo
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- Adam Pyzyna
- Sidney Tsai
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