Performance of new molecular resist in EUV lithography

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1. Introduction (motive force and previous work)
2. New molecular resist
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4. EUV imaging results
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Motive force

2005 ITRS Roadmap

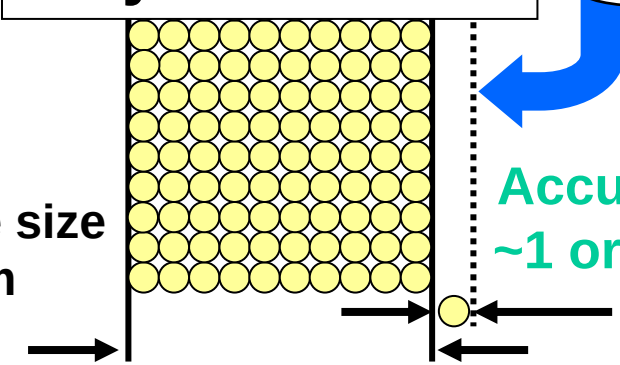
Table 77a Resist Requirements—Near-term Years

Year of Production	2005	2006	2007	2008	2009	2010	2011	2012	2013
DRAM ½ pitch (nm) (contacted)	80	70	65	57	50	45	40	36	32
Flash ½ pitch (nm) (un-contacted poly)	76	64	57	51	45	40	36	32	28
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	90	78	68	59	52	45	40	36	32
MPU gate in resist length (nm)	47	42	38	33	30	27	24	21	
Resist meets requirements for gate resolution and gate CD control (nm, 3 sigma) **†	3.3	2.9	2.6	2.3	2.1	1.9	1.7	1.5	1.3
Resist thickness (nm, single layer) ***	150–265	125–225	110–200	100–180	90–160	80–145	70–130	60–115	55–100
PEB temperature sensitivity (nm/C)	2	1.75	1.75	1.5	1.5	1.5	1.5	1.5	1
Backside particle density (particles/cm^2)	0.57	0.57	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Back surface particle diameter: lithography and measurement tools (nm)	160	120	120	120	100	100	100	100	75
Defects in spin-coated resist films (#/cm^2) †	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Minimum defect size in spin-coated resist films (nm)	50	45	40	35	30	30	20	20	20
Defects in patterned resist films, gates, contacts, etc. (#/cm^2)	0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02
Minimum defect size in patterned resist (nm)	50	45	40	35	30	30	20	20	20
LWR (3sigma) <8% of CD	4.2	3.8	3.4	3.0	2.7	2.4	2.1	1.9	1.7

† Noted exception for KrF in next three years: Solution NOT known, but does not prevent production manufacturing.

30-nm (2010~)

Polymeric resist

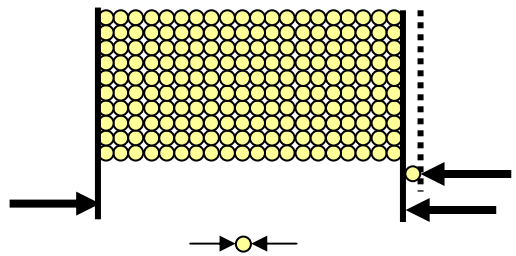


1 Molecule size ~3-4nm

Accuracy ~+/-2nm
~1 or 2 Molecules!

~10 Molecules!

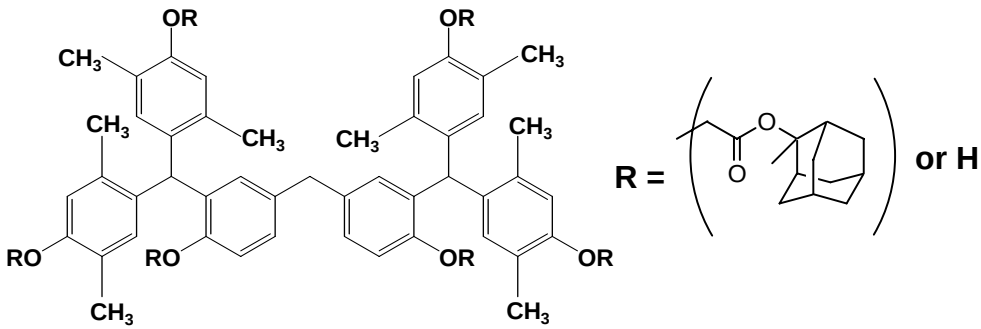
Molecular resist



1 Molecule size ~1-2nm

Resist based on low molecular weight polyphenol

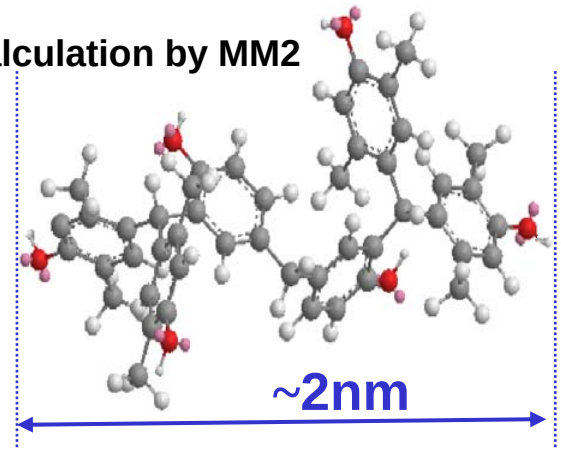
Previous Work*



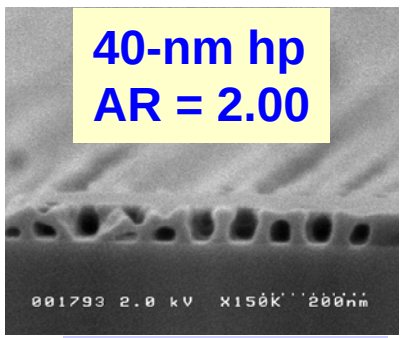
Polyphenol : 25X-MBSA-P

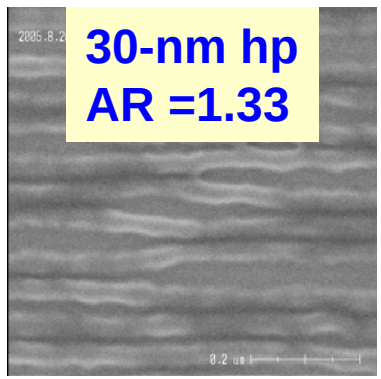
4,4'-methylenebis[2-[di(2,5-dimethyl-4-hydroxyphenyl)]methyl]phenol

calculation by MM2



*H. Oizumi et al., Microelectron. Eng. 83 (2006) 1107.

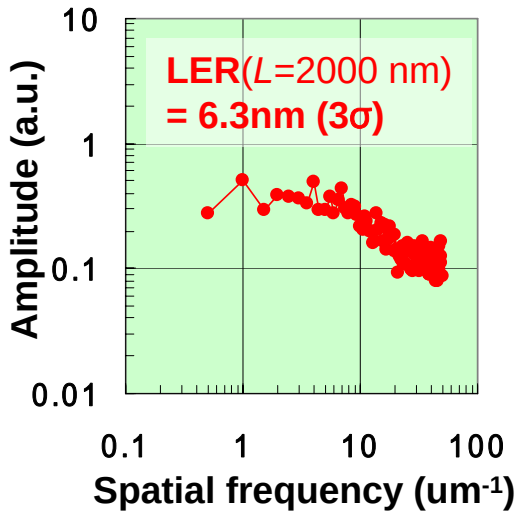




AR :aspect ratio

Exposure Dose : 10 mJ/cm^2

***Fourier amplitude spectra of LER for 50 nm L/S**



Resolution limit was determined by pattern collapse.

LER improvement concerning protecting group distribution

< HPLC analysis >

HLPC: High performance liquid chromatography

Crude Platform
(non to 4 parts protecting groups mixture)

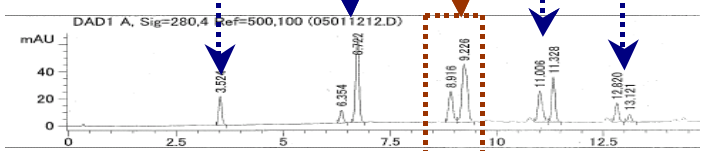
2 parts protecting

1 part protecting

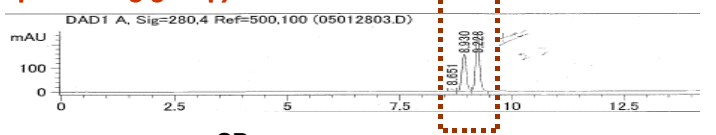
4 parts protecting

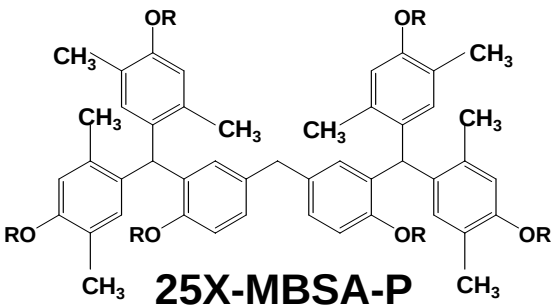
3 parts protecting

Non protecting

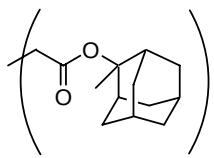


Purifying Platform
(only 2 parts protecting group)





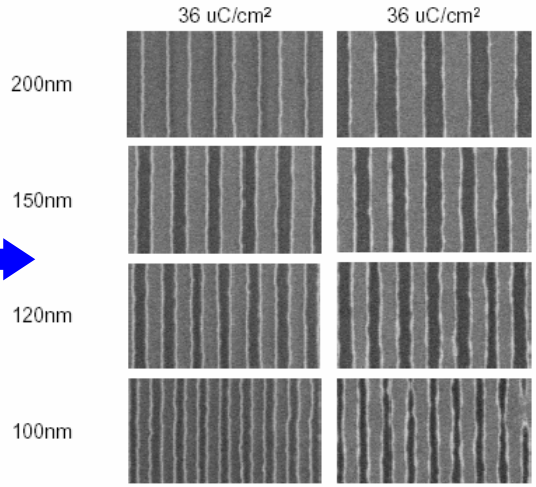
25X-MBSA-P

R =  or H

Resolution, LER
Purifying Platform >>> Crude Platform

Purifying Platform
(only 2 parts protecting group)

Crude Platform
(non to 4 parts protecting groups mixture)



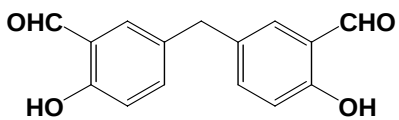
See D. Shiono poster (06-RE-61)

Controlling distribution of protecting groups have a great impact on improvement of LER

Design and synthesis of a new partially-protected polyphenol

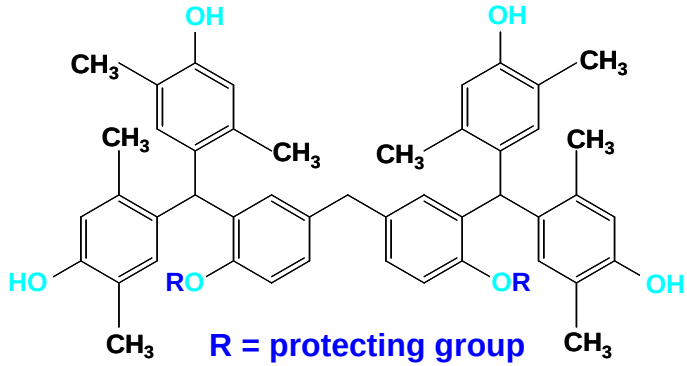
New Base Resin

Synthesis scheme



Phenol compound

4 steps



R = protecting group
(only 2 parts protecting group)

25X-MBSA-M

Monodispersion

See D. Shiono poster (06-RE-61)

Reduction in LER ← ***Specified number of protecting groups***

Increase in intermolecular interaction ← ***Specified position of protecting groups***

High-NA Small-Field Exposure Tool (HINA)

(1) Wavelength: 13.5nm (SR: Super-ALIS, SBL-1)

(2) Two-aspherical-mirror projection optics

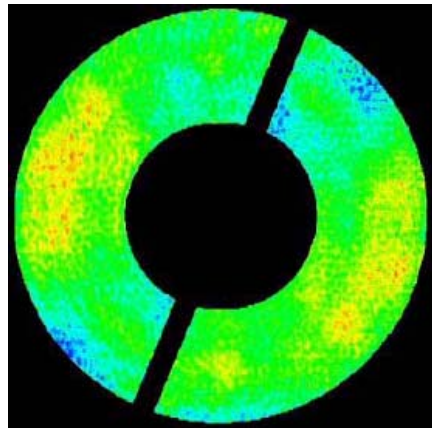
Magnification: 1/5, NA：0.3, field size: 0.5mm x 0.3mm

(3) Two illumination systems

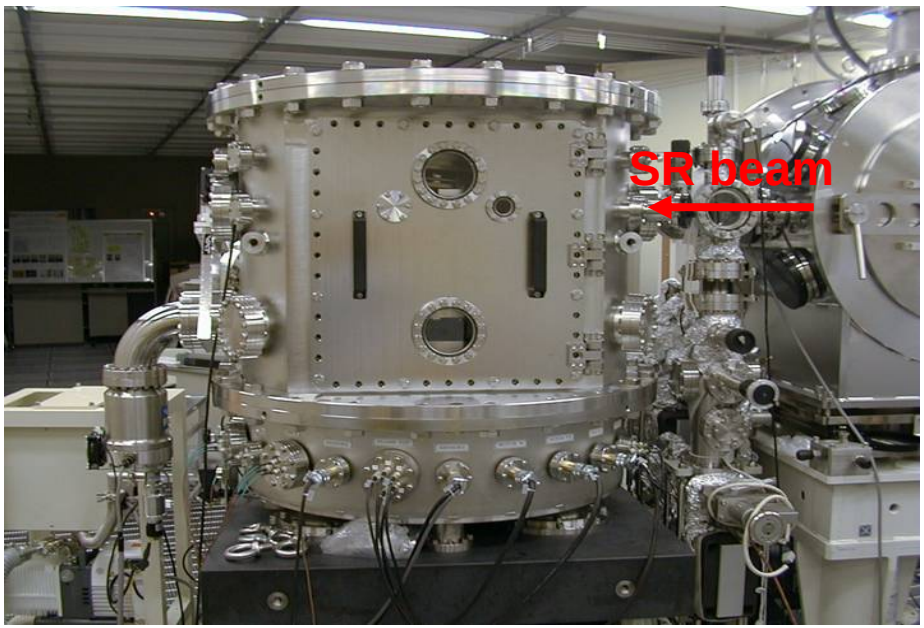
Koehler illumination with $\sigma \approx 0.8$ (Normal, Annular)

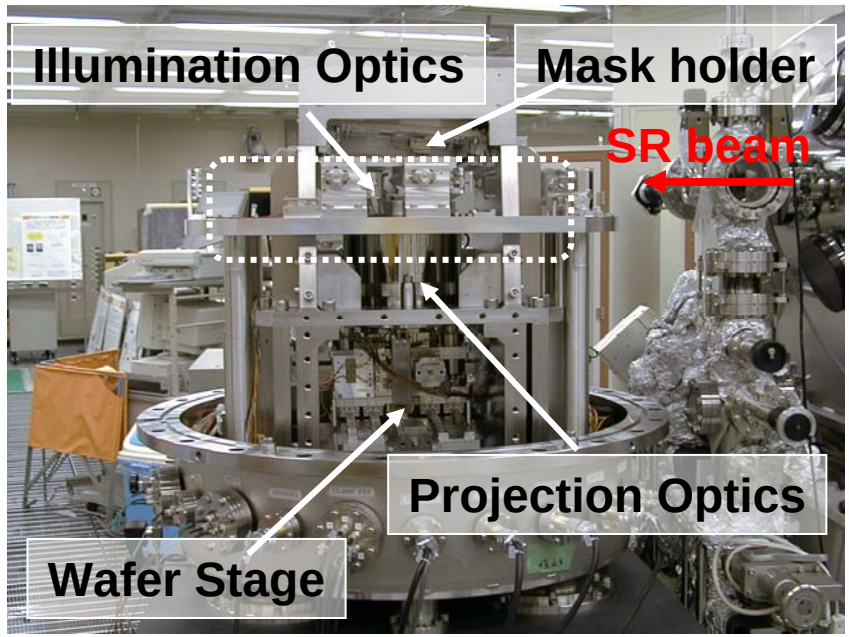
coherent illumination with $\sigma \approx 0$

(4) Mask size: 6025 reticle; Wafer size: 8”ϕ.



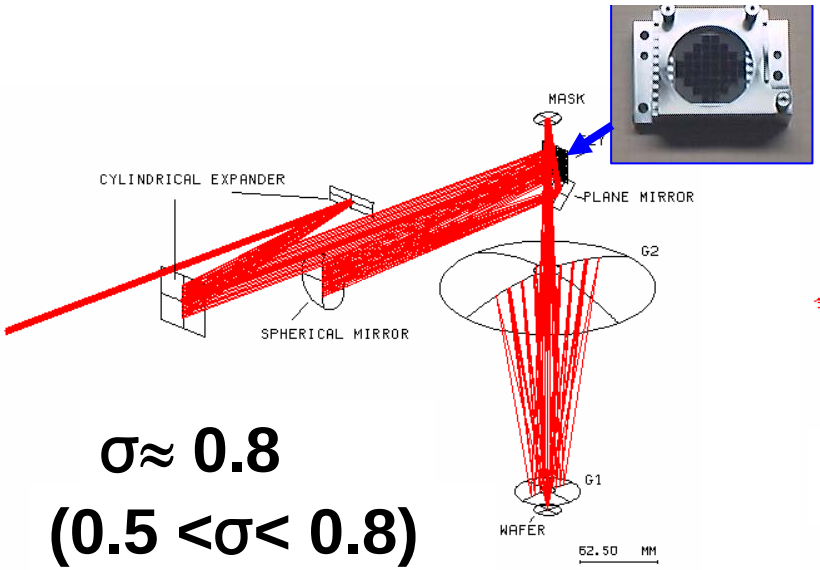
WFE of HINA set-3: 0.91 nm RMS.(λ/15)



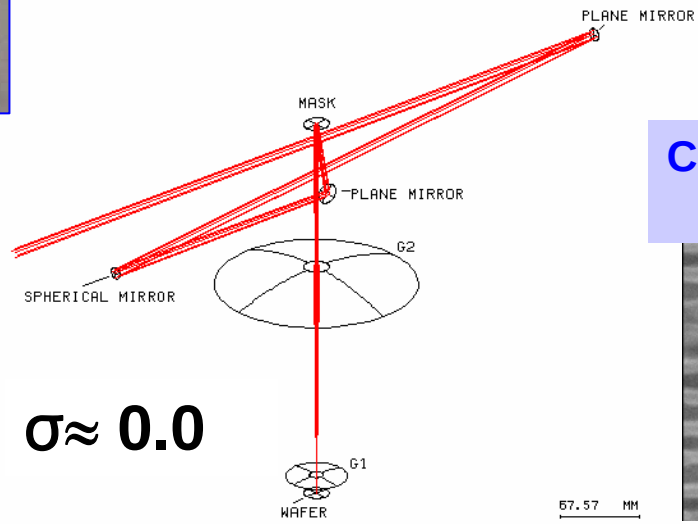


Illumination optics of HINA (σ ≈ 0.8, 0.0)

Fly-eye mirror

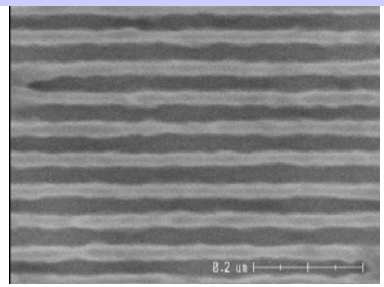


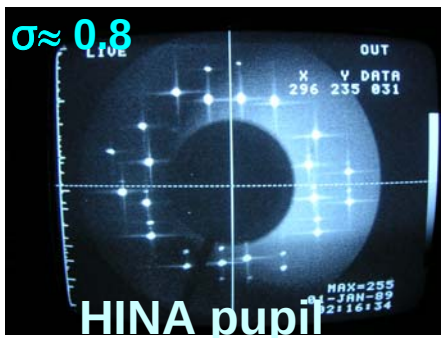
σ≈ 0.8
(0.5 <σ< 0.8)

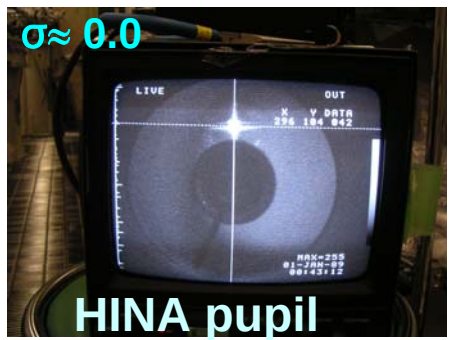


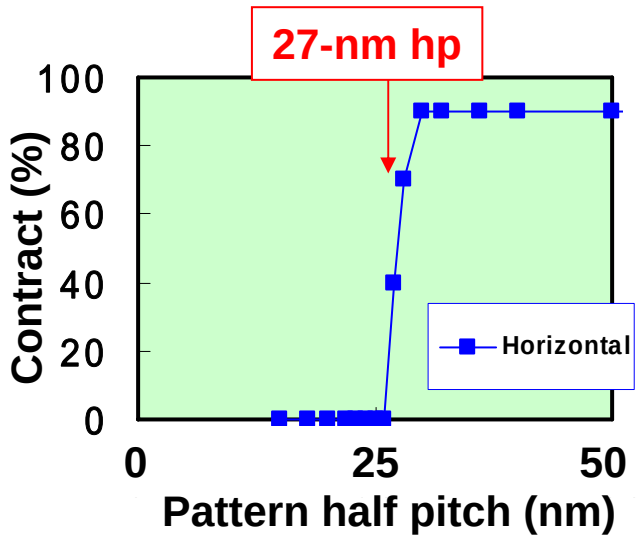
σ≈ 0.0

CA polymeric resist
28-nm hp









Specifications of Pattern Replications

Reflection Mask: Mo/Si d-spacing = 7 nm, 40 pairs

Absorber and buffer : 65 ~ 90-nm-thick TaGeN and 10-nm-thick Cr

Resist System :Mono-disperse Polyphenol (25X-MBSA-M)

+ PAG + Base

Resist film Thickness : (58 ~ 100-nm-thick on Si wafers)

Exposure :Illumination condition:$\sigma \approx 0$

PAB: 110 ℃ 90 sec.

PEB : 100 ℃ 90 sec.

Development: TMAH 2.38% 30 sec.

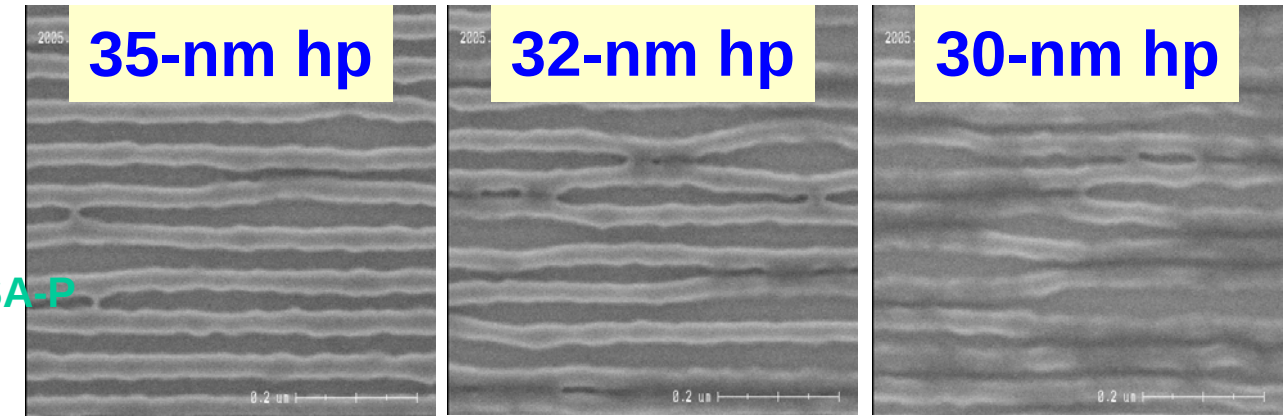
Rinse: Deionized H_2O (without surfactant) 30 sec.

SEM: S9380, S5000(Hitachi)

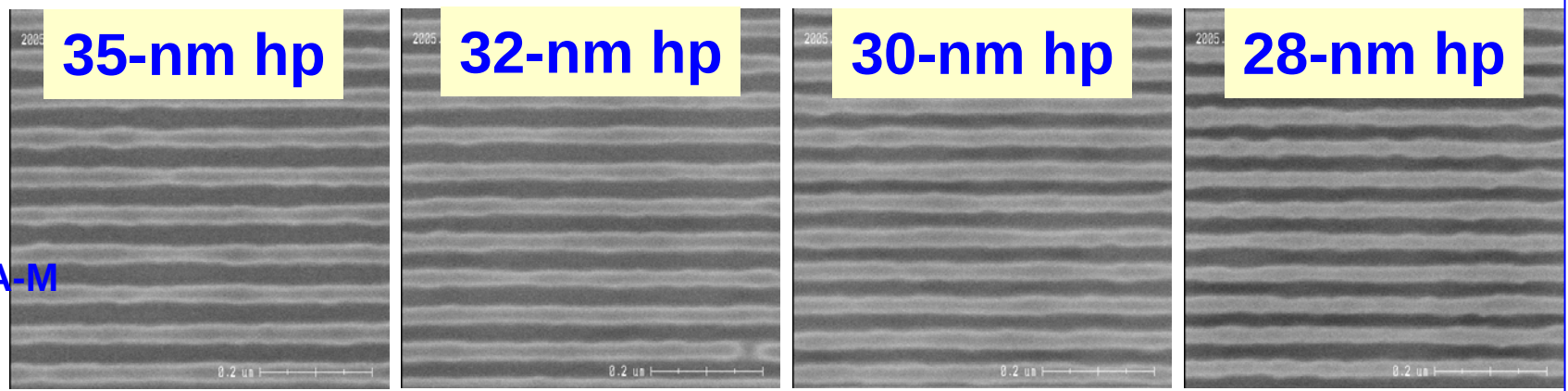
Sub-40nm resolution: Top view

Resist film thickness: 40 nm^t
Exposure Dose : 10.0 mJ/cm^2

Previous Resist 25X-MBSA-P



New Resist 25X-MBSA-M

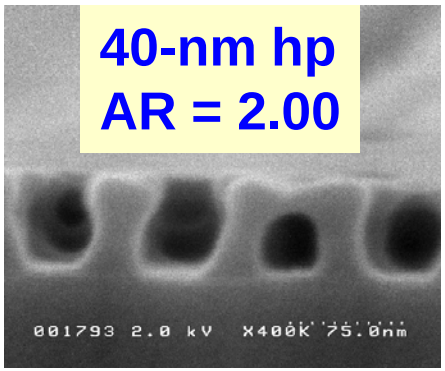


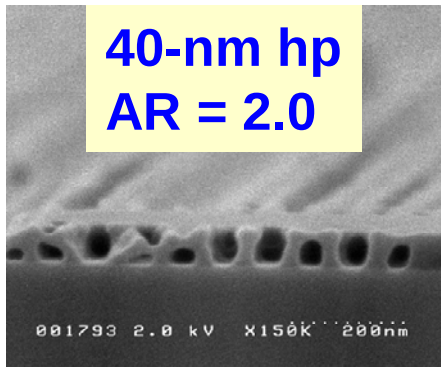
Resist film thickness: 58 nm^t
Exposure Dose : 12.2 mJ/cm^2

28-nm hp patterns were resolved.

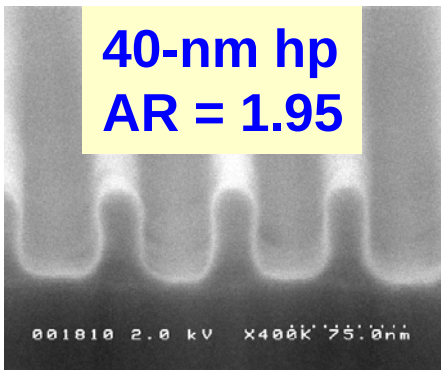
Resolution: Cross-sectional view

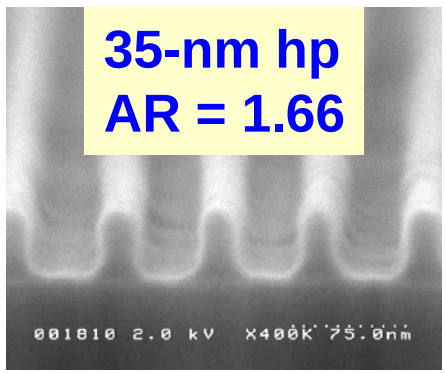
Previous resist (25X-MBSA-P)

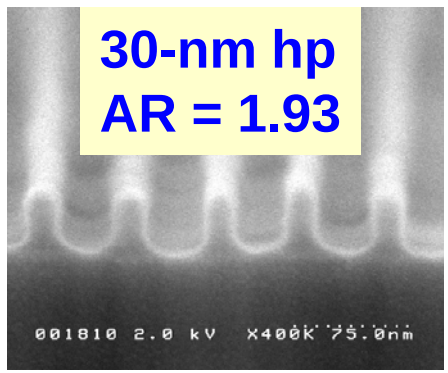


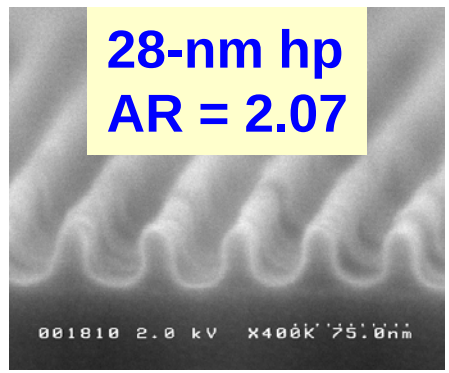


AR: Aspect Ratio









New resist (25X-MBSA-M)

Pattern collapse was markedly improved.

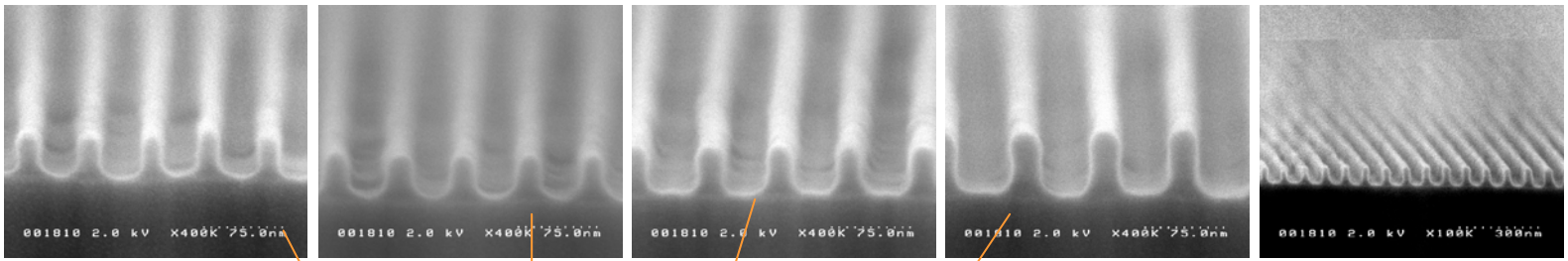
Improvement in pattern collapse

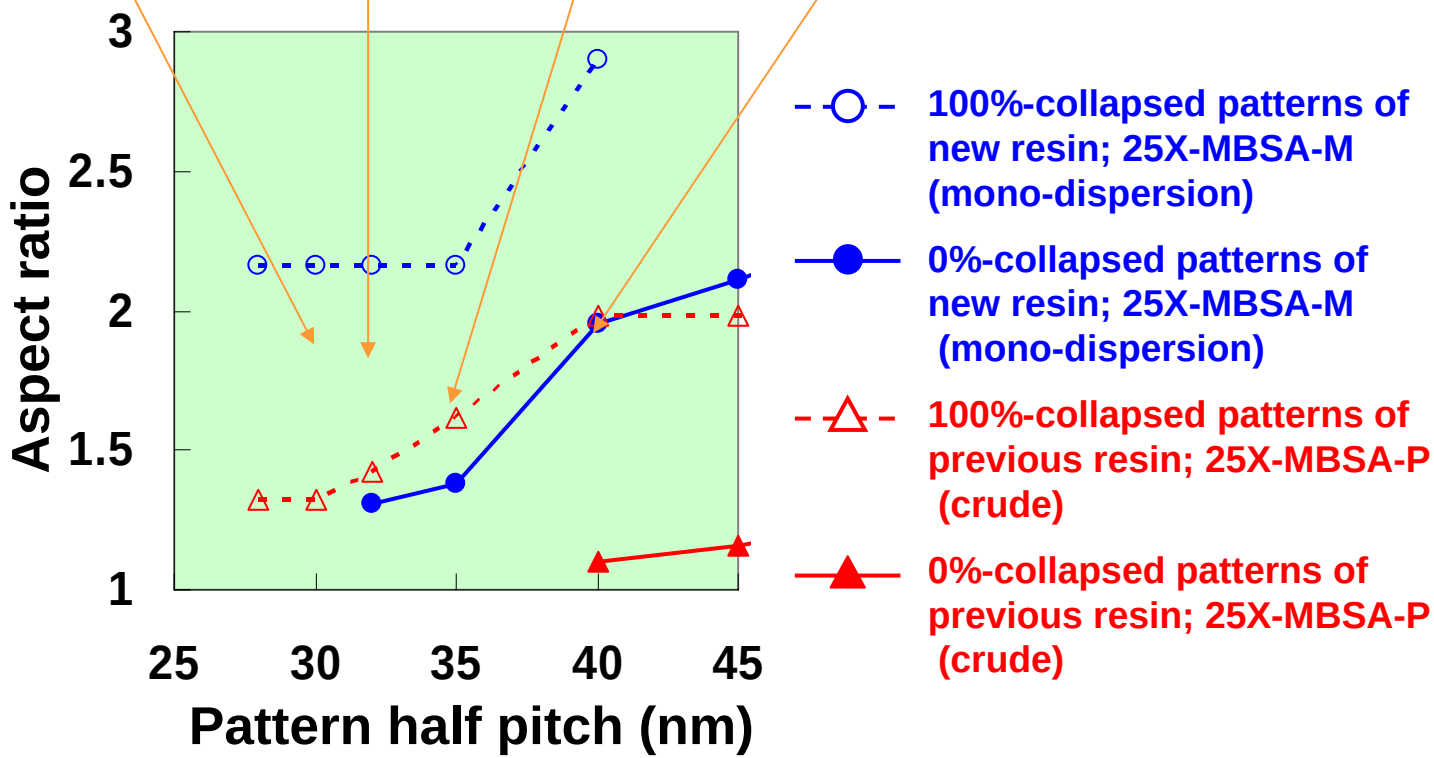
30-nm hp
AR = 1.93

32-nm hp
AR = 1.81

35-nm hp
AR = 1.66

40-nm hp
AR = 1.95





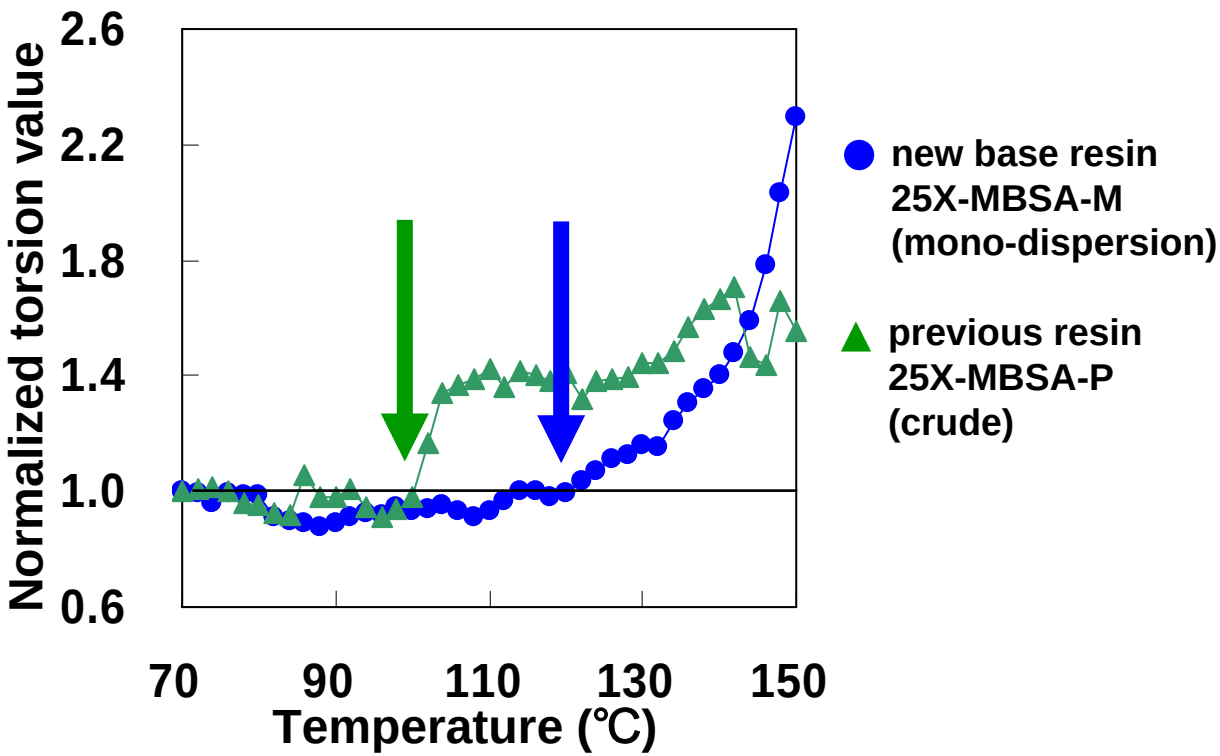
Glass transition temperature evaluated by FFM*

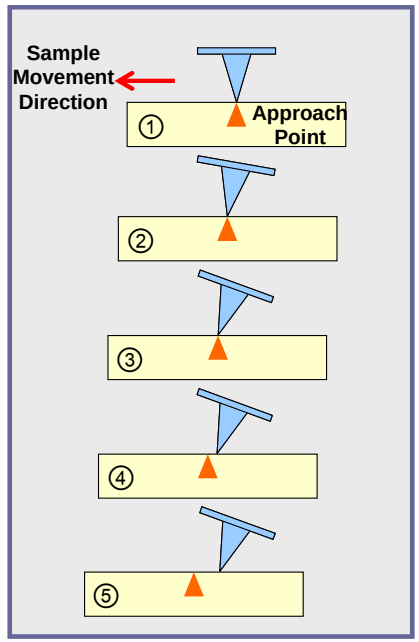
Tg :Glass Transition Temperature

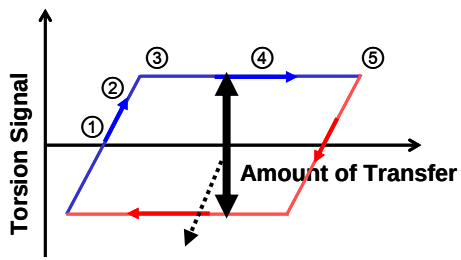
*FFM :Frictional Force Microscopy
E-Sweep (SII Nanotechnology Inc.)

*T. Kajiyama et al. :*Macromolecules*, 27 (1994) 7932.

New base resin (mono-dispersion) surface started to soften up at a temperature of about 120℃.





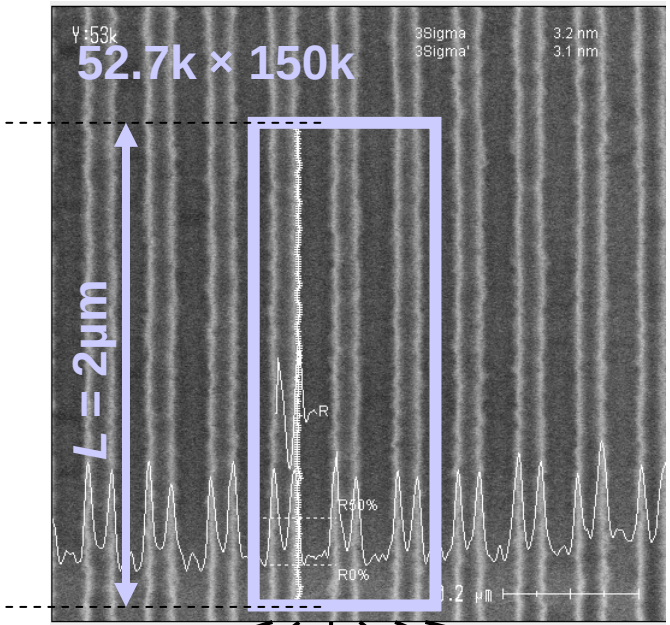


Differential Torsion Signal (V)

LER analysis

New resist (25X-MBSA-M)

45-nm hp



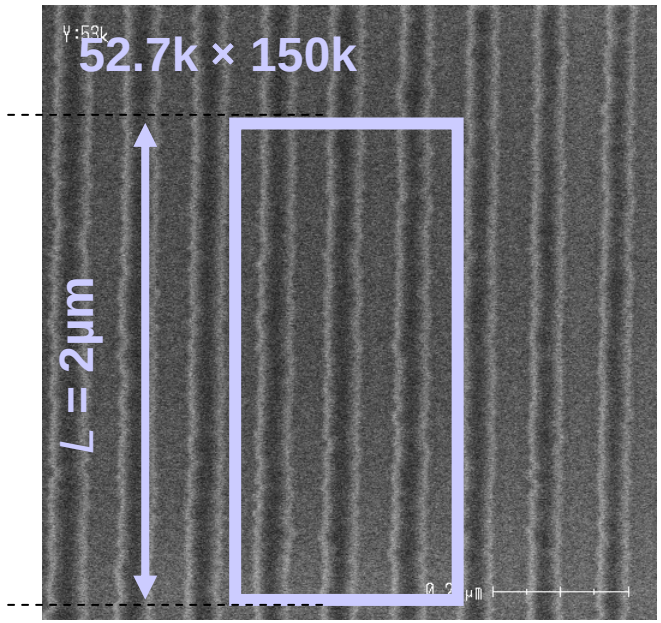
3.5nm 3.2nm 3.9nm 4.1nm 3.5nm 3.5nm

LER : 3.6nm (3σ)

(*L* = 2μm, measuring points;200)

Previous resist (25X-MBSA-P)

50-nm hp

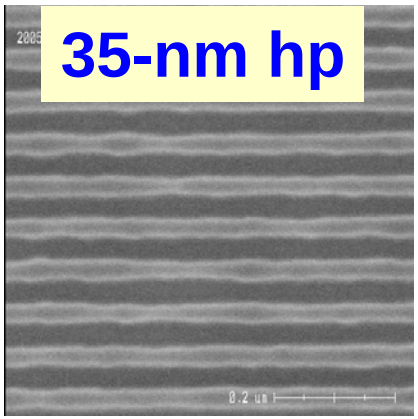


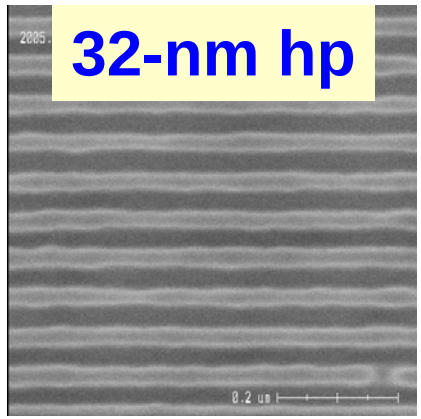
LER : 6.3nm (3σ)

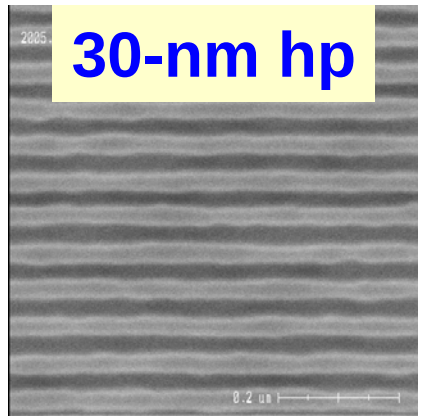
(*L* = 2μm, measuring points;200)

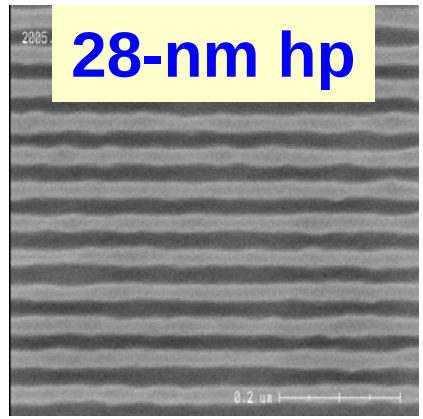
Sensitivity Enhancement (Road to 5 mJ/cm^2)

Exposure Dose : 12.2 mJ/cm^2 **Resist film thickness: 58 nm^t**

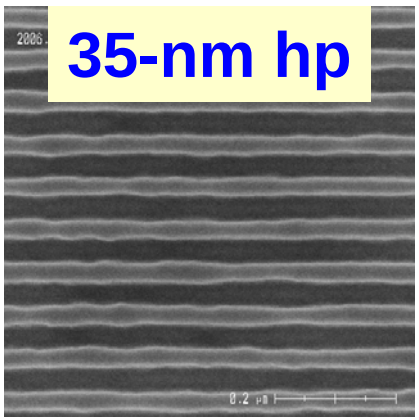


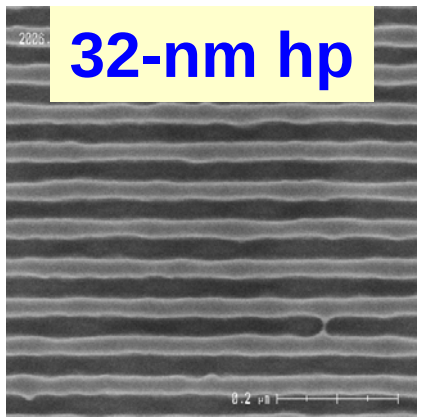


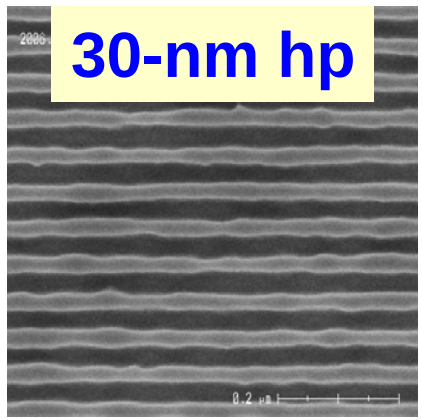


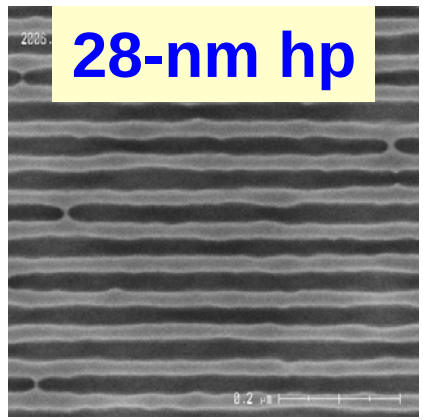


Exposure Dose : 5.3 mJ/cm^2







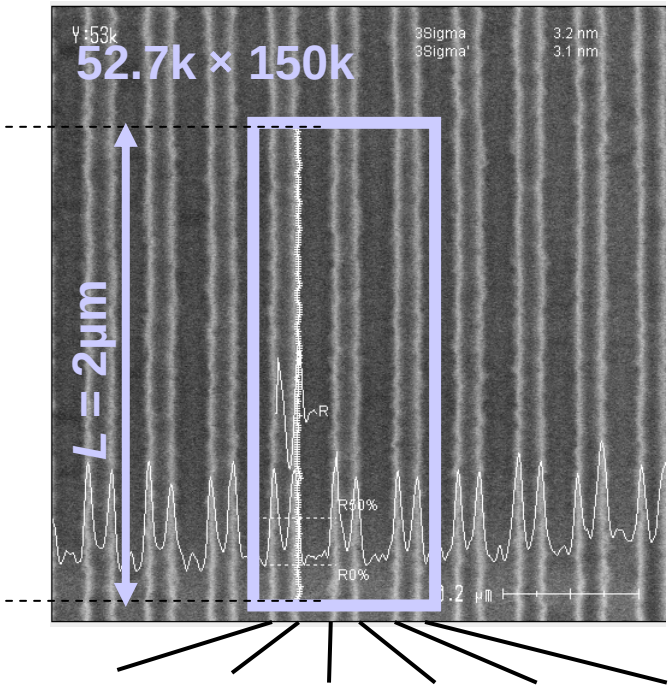


28-nm hp patterns were resolved.

Sensitivity Enhancement (Road to 5 mJ/cm^2):LER

Exposure Dose : 12.2 mJ/cm^2

45-nm hp



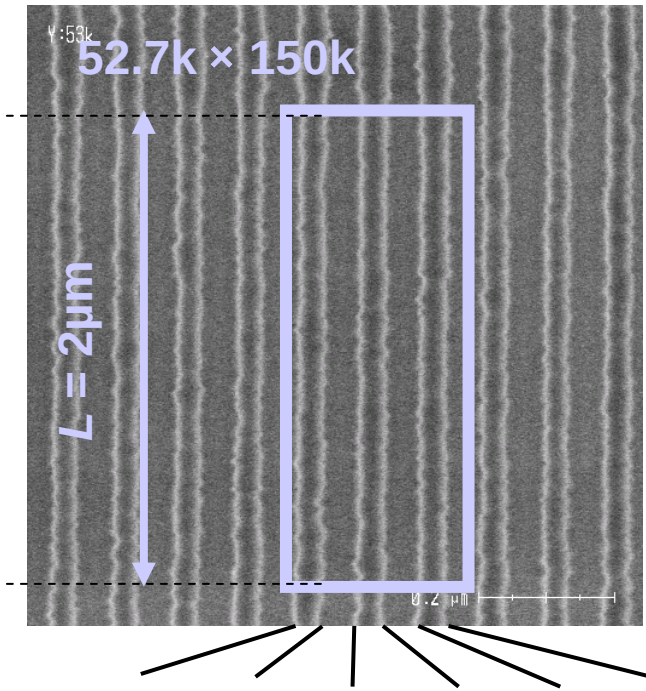
3.5nm 3.2nm 3.9nm 4.1nm 3.5nm 3.5nm

LER : 3.6nm (3σ)

(*L* = 2μm, measuring points;200)

Exposure Dose : 5.1 mJ/cm^2

45-nm hp



6.3nm 6.5nm 4.6nm 5.7nm 5.1nm 6.7nm

LER : 5.8nm (3σ)

(*L* = 2μm, measuring points;200)

Summary

We examined ultimate fine-pitch pattering performance in EUVL of a chemically amplified positive-tone resist based on low-molecular-weight amorphous polyphenol (25X-MBSA-M) for which the position and number of protected hydroxyl groups have no dispersion.

1．The new resist (58nm^t) provides a resolution of 28-nm hp at an exposure dose of 5.3mJ/cm^2 and a high aspect ratio of 2.

2．*Pattern collapse was markedly improved.*
The new polyphenol resin surface started to soften up at a temperature of about 120℃.

3．LER (*L*=2.0μm) of 3.6nm (3σ) @12.2 mJ/cm^2 and 5.8nm (3σ) @5.1 mJ/cm^2 was achieved.

Next Issues

・ High sensitivity (5mJ/cm^2) and LER, ・ Footing profile

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