EUV Resist Process Development at EIDEC

EUVL Infrastructure Development Center Inc.

Eishi Shiobara, Norihiko Sugie, Toshiya Takahashi, Yukiko Kikuchi, Ryuji Onishi, Julius Santillan, Hiroyuki Tanaka, Shunko Magoshi and Toshiro Itani

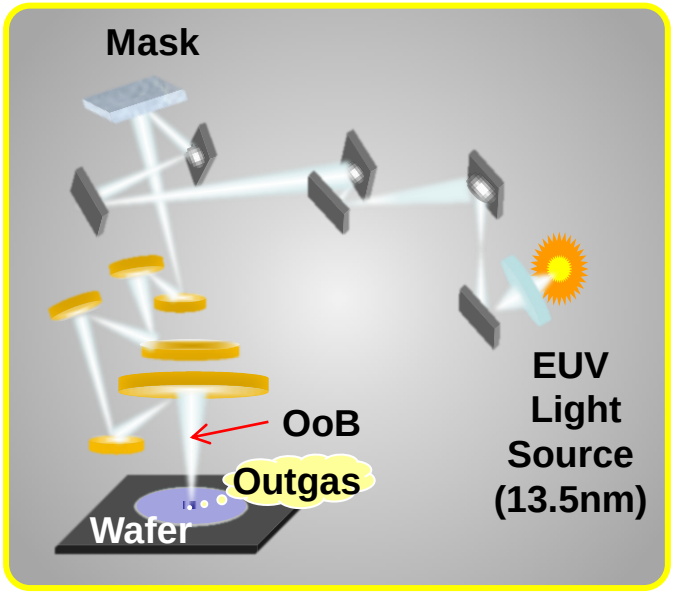
2012 International Symposium on Extreme Ultraviolet Lithography Oct. 3, 2012

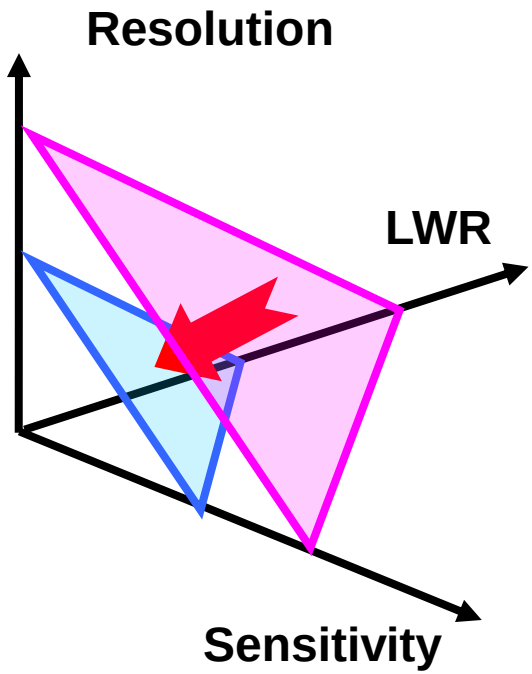
Outline

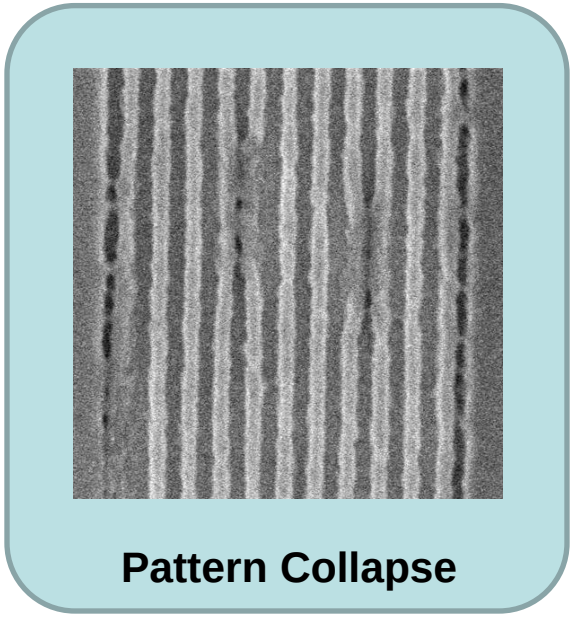
1. Introduction
2. Selection of EIDEC Standard Resist
3. Process Investigation to Reduce LWR
   - Surfactant Rinse Process
4. Fundamental Study of Development Process
   - High Speed AFM (HS-AFM)
5. Summary

Introduction

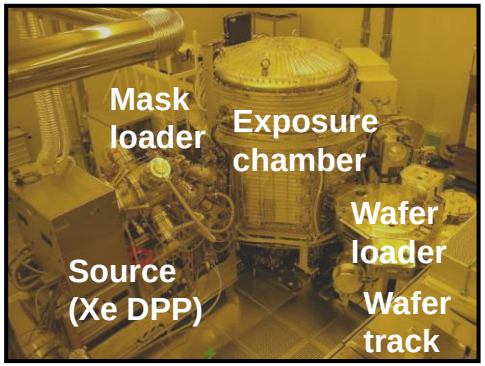
Issues of EUV resist for 16 nm half pitch







- Trade-off relationship among Resolution, LWR and Sensitivity (RLS)
- Resist outgassing
- Out of Band (OoB)
- Pattern collapse

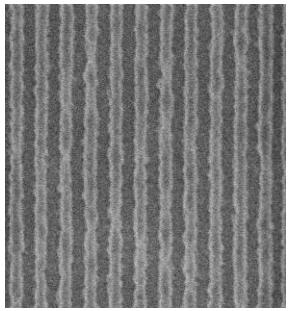
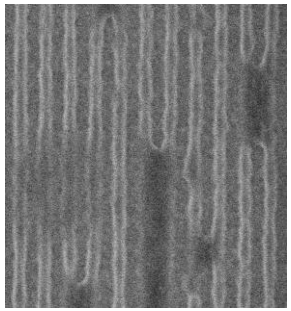
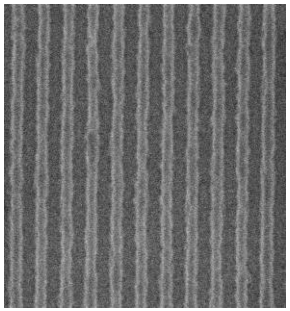


Small Field Exposure Tool (SFET)

Outline

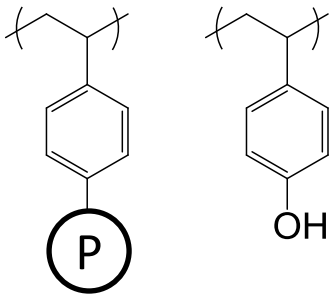
1. Introduction
2. Selection of EIDEC Standard Resist
3. Process Investigation to Reduce LWR
   - Surfactant Rinse Process
4. Fundamental Study of Development Process
   - High Speed AFM (HS-AFM)
5. Summary

Performance of EUV Model Resists

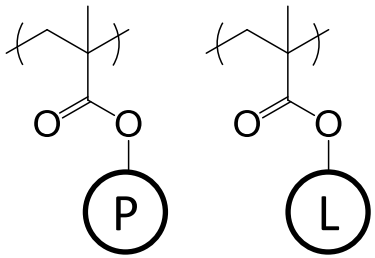
	Model resists	PHS base	Methacryl base	Hybrid
R	Resolution (nm)	<26	32	<26
L	LWR (nm)	7.4	-	6.8
S	Sensitivity (mJ/cm^2)	18	17	17
	Pattern Size: 30nm (Top-Down SEM image)			

Tool=SFET
NA=0.3,
Illu.=Annular
F.T. = 50nm

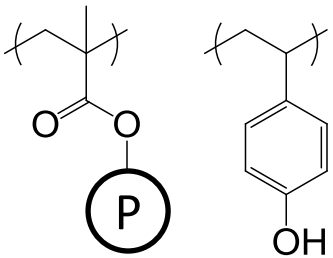
PHS base resist



Methacryl base resist

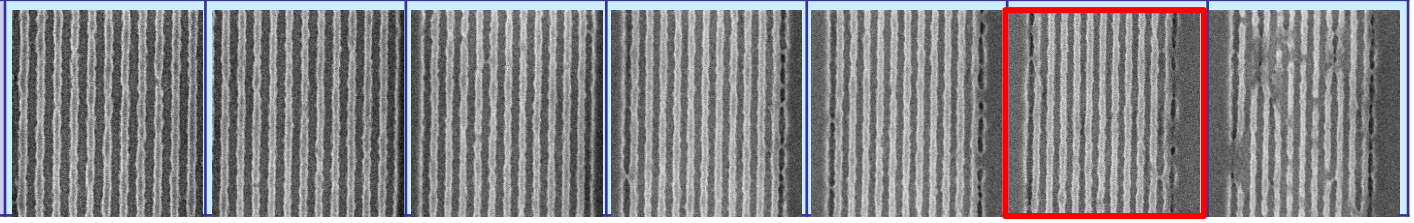


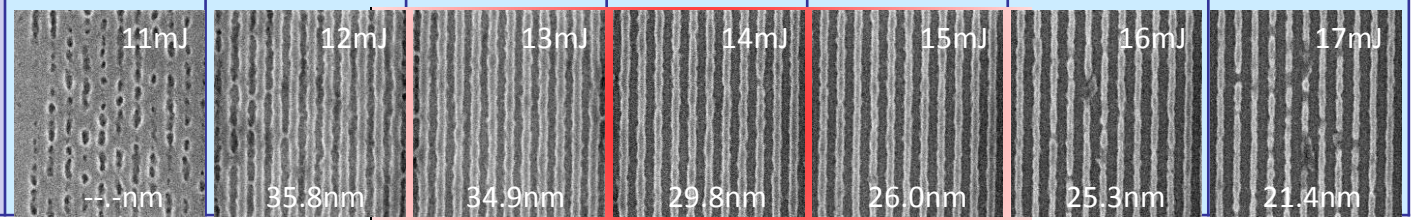
Hybrid resist



Fundamental study showed to need optimization to improve resolution.

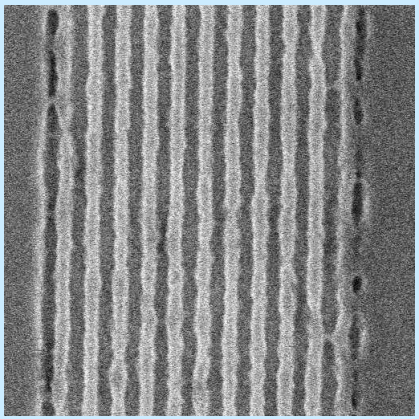
EIDEC Standard Resist : ESR1

Half Pitch (nm)	30	28	26	25	24	23	22
Resolution limit:							

Exp. Dose (mJ/cm^2)	11	12	13	14	15	16	17
Exposure Latitude: 12.6% @ 30nm L/S							

Evaluation conditions
Exposure tool：SFET
（NA=0.3, Annular）
Resist thickness：50nm

	ESR1	
R	Resolution (nm)	23
L	LWR (nm)	7.4
S	Sensitivity (mJ/cm^2)	14

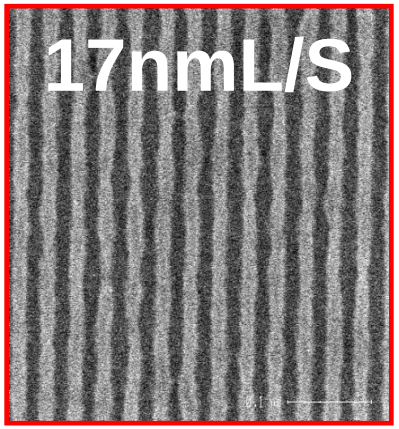


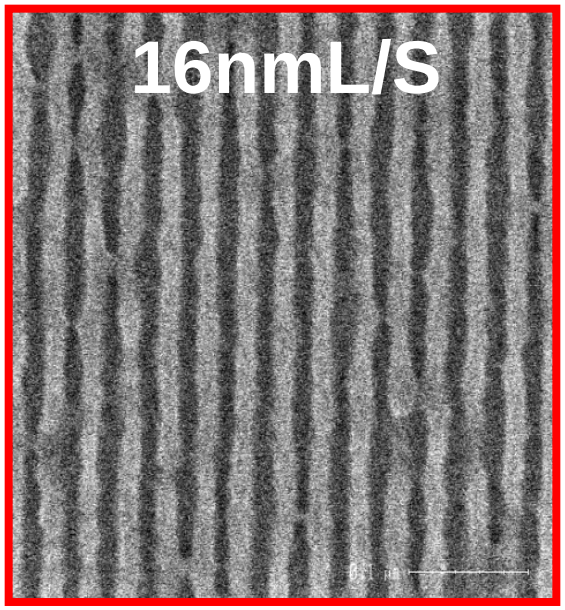
23nm L/S

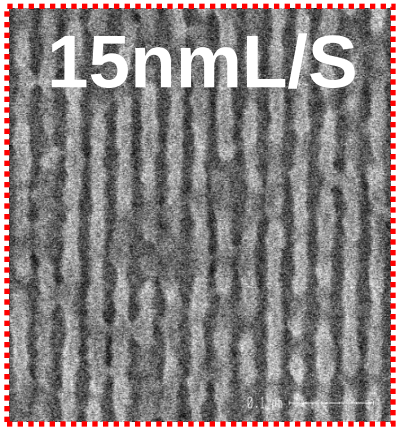
1st EIDEC standard resist (ESR1) was selected for process evaluations.

Norihiko Sugie, et. al., **P-RE-09**

Resolution Limit of Chemically Amplified Resist





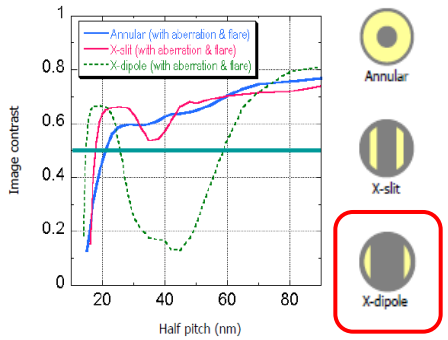


Evaluation conditions

Exposure tool：SFET

（NA=0.3, Illumination=X-dipole）

Resist film thickness：35nm

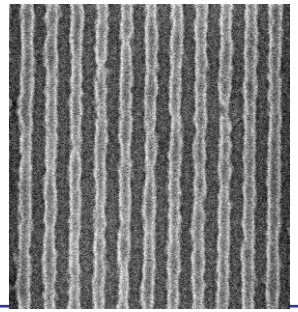
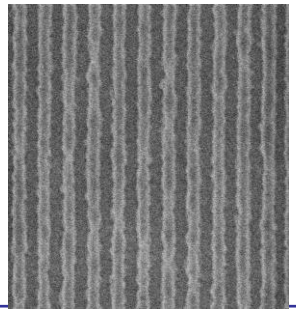
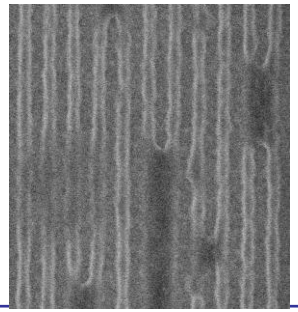
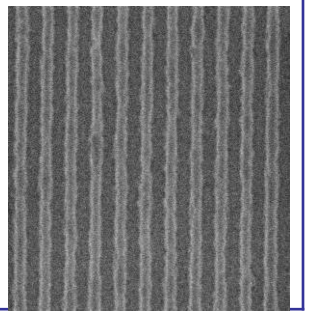


Proc. of SPIE Vol. 7696 79690Q-6

Illumination modes and image contrast

16 nm L/S pattern was resolved by SFET X-dipole illumination.

Comparison of Resist Performances

	ESR1	Model resists		
		PHS base	Methacryl base	Hybrid
Resolution (nm)	23	<26	32	<26
LWR (nm)	7.4	7.4	-	6.8
Sensitivity (mJ/cm^2)	14	18	17	17
Pattern Size: 30nm (Top-Down SEM image)				

R L S

ESR1 shows good resolution and sensitivity. However LWR is still large compared to the hybrid model resist.

Resist process investigation to reduce LWR

Outline

1. Introduction
2. Selection of EIDEC Standard Resist
3. Process Investigation to Reduce LWR
   - Surfactant Rinse Process
4. Fundamental Study of Development Process
   - High Speed AFM (HS-AFM)
5. Summary

Surfactant Rinse Process to Reduce LWR

Process candidates:

- Post Baking process
- Surfactant rinse process
- Plasma treatment process

Expected effects of Surfactant rinse:

- Reduction of LWR
- Suppression of pattern collapse

Evaluation conditions

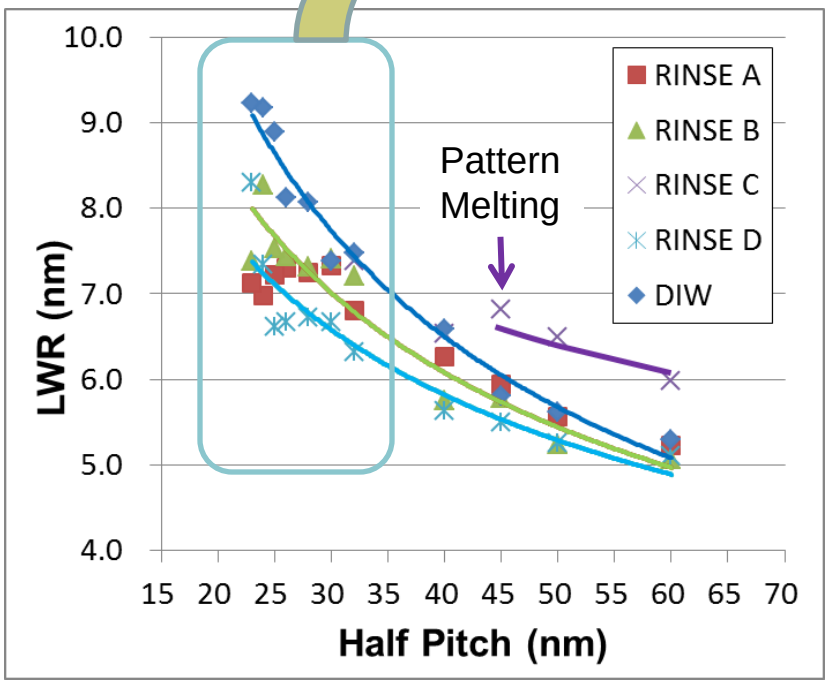
Exposure tool : SFET
(NA=0.3, Illumination=Ann.)
Resist : ESR1 (60nm)
(to emphasize pattern collapse)
Substrate : bare-Si with HMDS

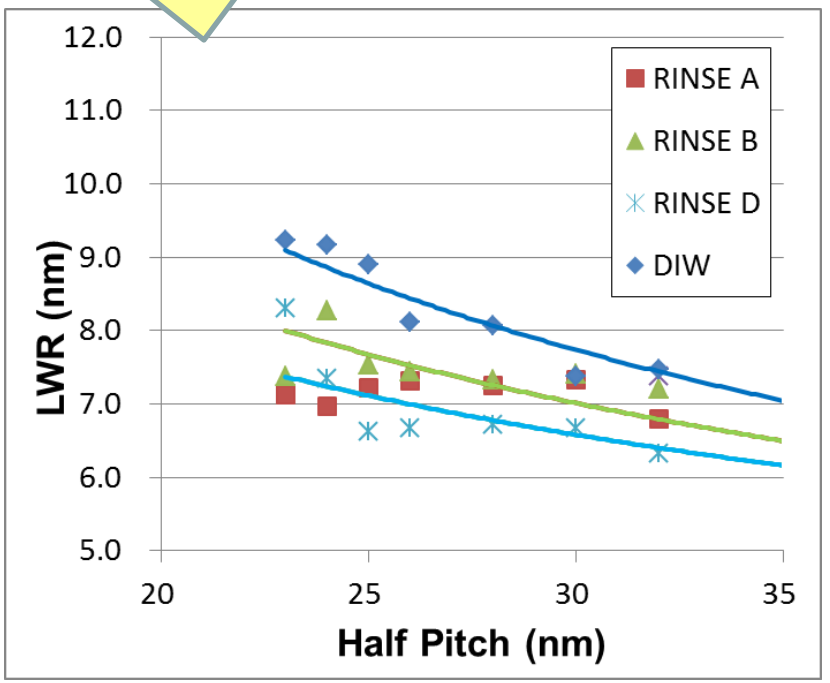
	D.I.W (Ref.)	Rinse A	Rinse B	Rinse C	Rinse D
Base solution	-	for EUV resist		for ArF Imm. resist	
Surfactant Concentration	-	Standard	50% Diluted	Standard	50% Diluted
Surface Tension (mN/m)	73	37	41	33	37
Process	Straight Nozzle 35sec	DIW : Straight Nozzle, 15sec Rinse : manual dispense, 100cc, 20sec			

LWR Evaluation for Surfactant Rinse Process

Exposure Tool : SFET （0.3NA, Ann.）
Resist : ESR1 (60nm)

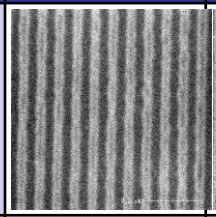
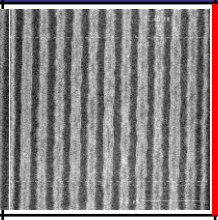
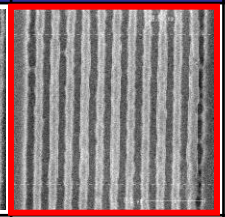
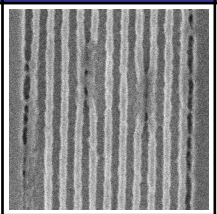
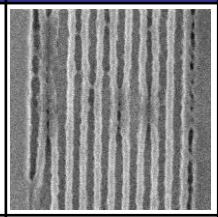
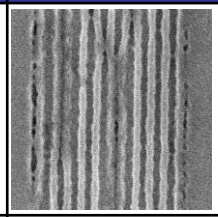
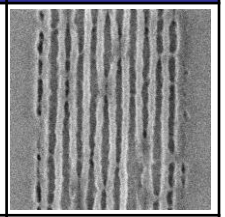
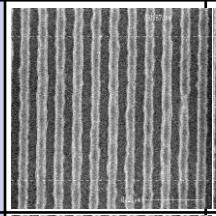
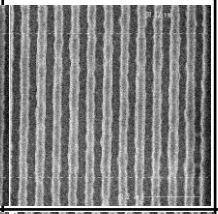
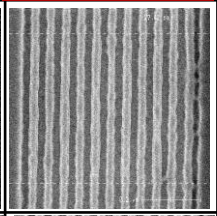
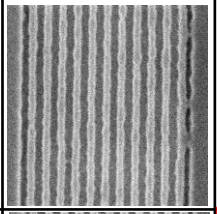
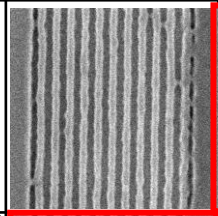
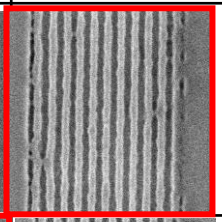
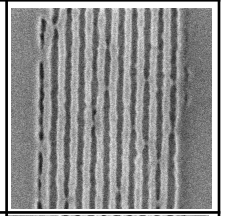
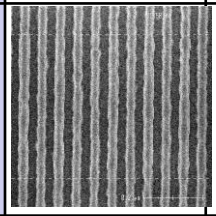
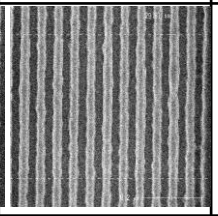
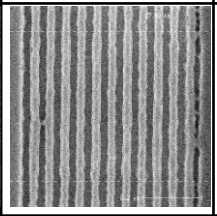
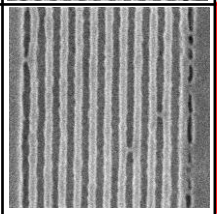
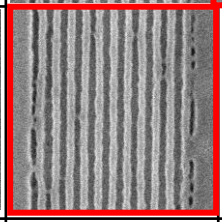
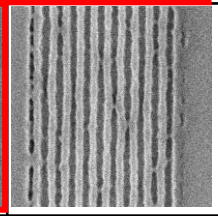
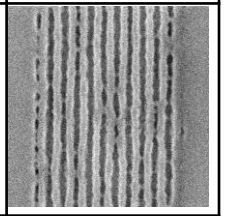
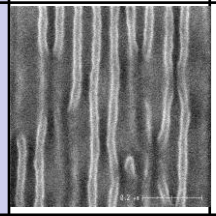
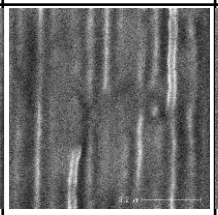
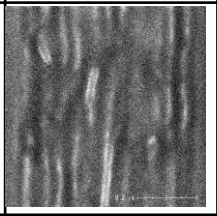
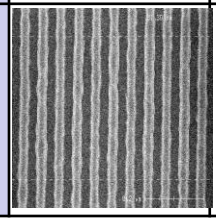
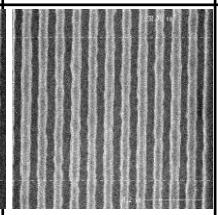
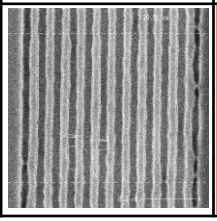
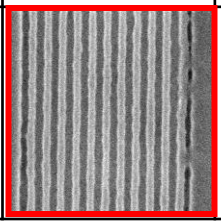
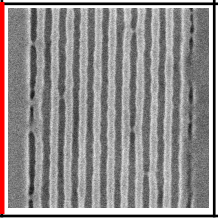
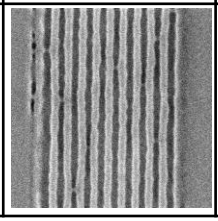
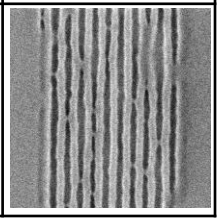
LWR of various half pitch pattern





LWR were improved near resolution limit by using surfactant rinse.

Resolution limits using Surfactant Rinse

	30n L/S	28nm L/S	26nm L/S	25nm L/S	24nm L/S	23nm L/S	22nm L/S
D.I.W (Ref.)							
Rinse A							
Rinse B							
Rinse C				No Data	No Data	No Data	No Data
Rinse D							

Resolution limit was improved by using rinse solutions.

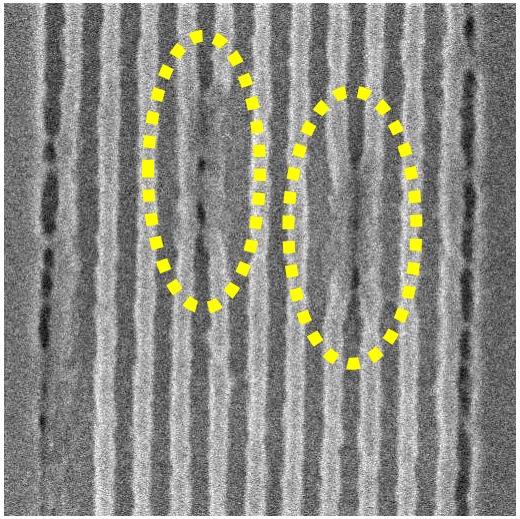
The Effects of Surfactant Rinse Process

Pattern collapse mode

Top down image

D.I.W

25 nm L/S

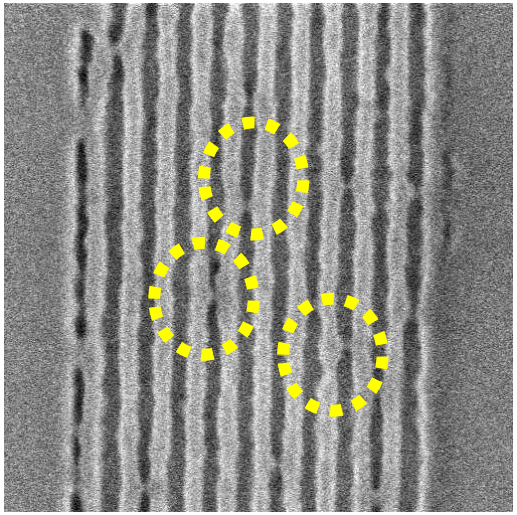


1. Pattern collapse **in long range**
2. High frequency roughness

Surfactant Rinse

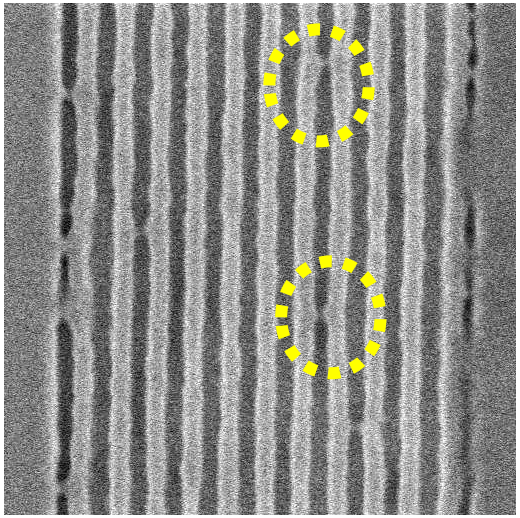
Rinse A

22 nm L/S



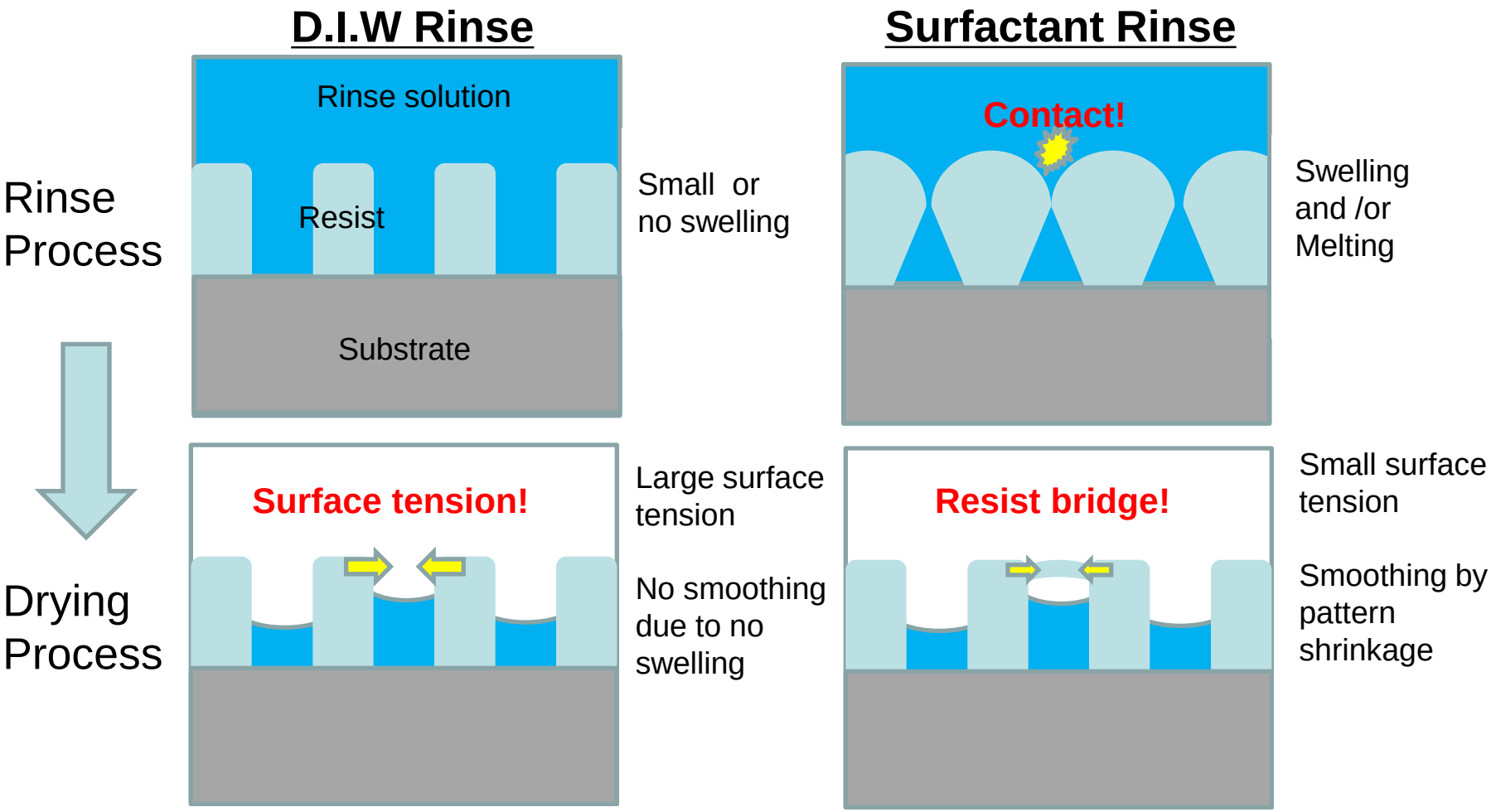
Rinse D

24 nm L/S



1. Pattern collapse and/or resist bridge **in short range**
2. Less of high frequency roughness

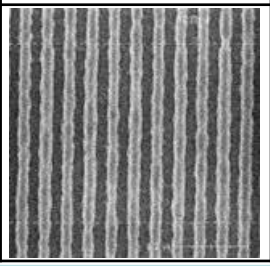
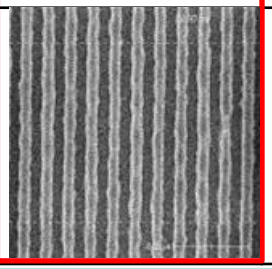
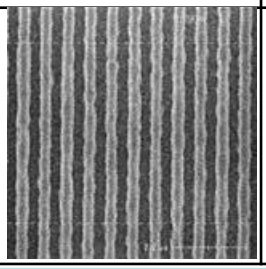
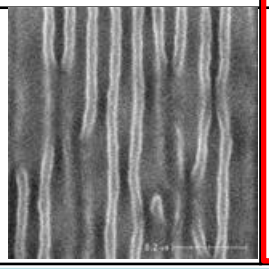
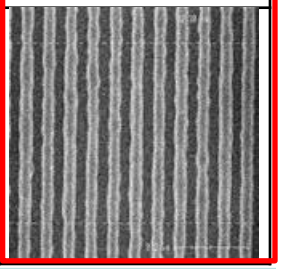
Model of The Effect of Surfactant Rinse



1. Patten collapse **in long range**
2. High frequency roughness

1. Patten collapse **in short range**
2. Less of high frequency roughness

Summary of Evaluation Results

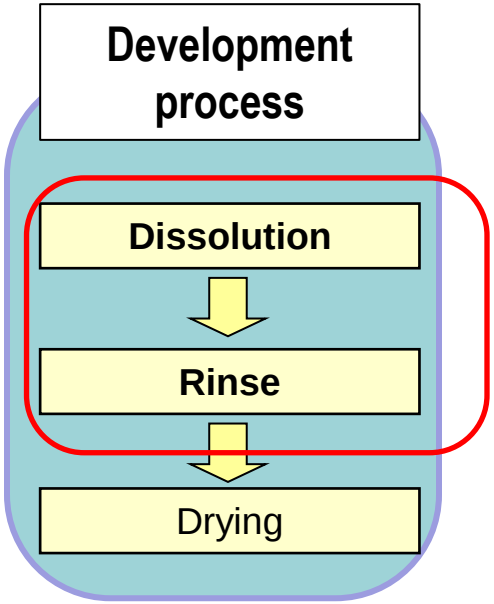
		D.I.W (Ref.)	Rinse A	Rinse B	Rinse C	Rinse D
	Base solution	-	for EUV resist	←	for ArF Imm. resist	←
	Surfactant Concentration	-	Standard	50% Diluted	Standard	50% Diluted
	Surface Tension (mN/m)	73	37	41	33	37
R	Resolution Limit (nm LS)	26	23	24	32	25
L	LWR @30nm (nm)	7.8	7.5	7.6	Melting	6.9
S	Sensitivity @30nm (mJ/cm2)	20.0	20.3	20.7	Melting	20.7
	Pattern Size 30nm Half pitch (Top-Down SEM image)					

•Optimization of swelling and/or melting by surfactant rinse might be important.

Outline

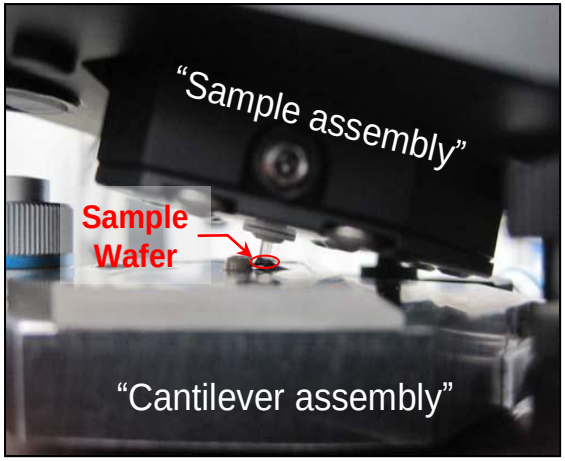
1. Introduction
2. Selection of EIDEC Standard Resist
3. Process Investigation to Reduce LWR
   - Surfactant Rinse Process
4. Fundamental Study of Development Process
   - High Speed AFM (HS-AFM)
5. Summary

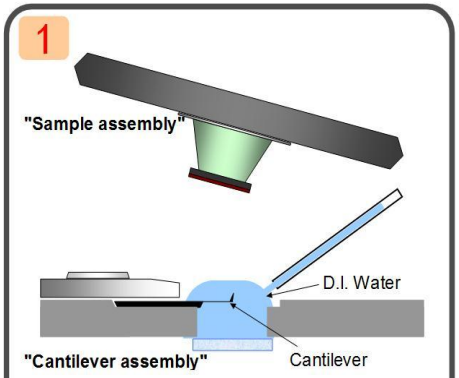
In situ analysis using high speed atomic force microscopy (HS-AFM)



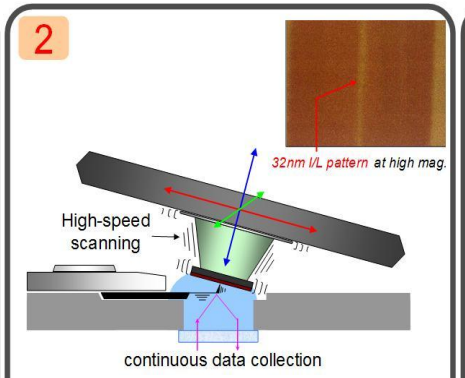
In situ analysis

HS-AFM tool: Nano Explorer (NEX)

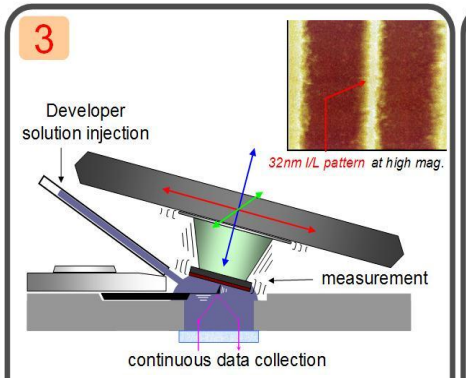




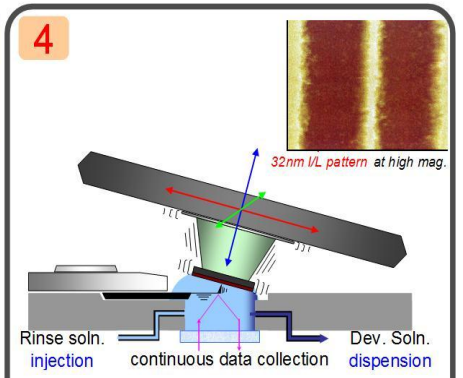
Preparation of sample / cantilever assembly



Start of high-speed scanning



In situ dissolution analysis



In situ rinse analysis (continuous flow)

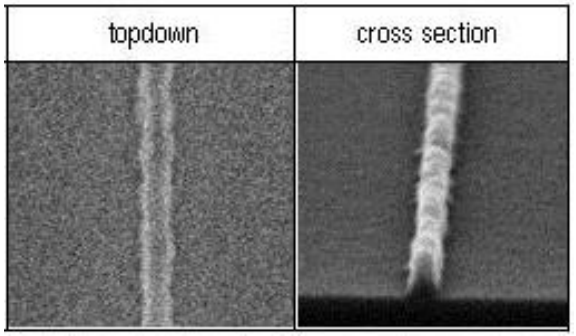
In situ analysis of resist dissolution and rinse processes were done for typical resists.

Julius Santillan, et. al., P-RE-08

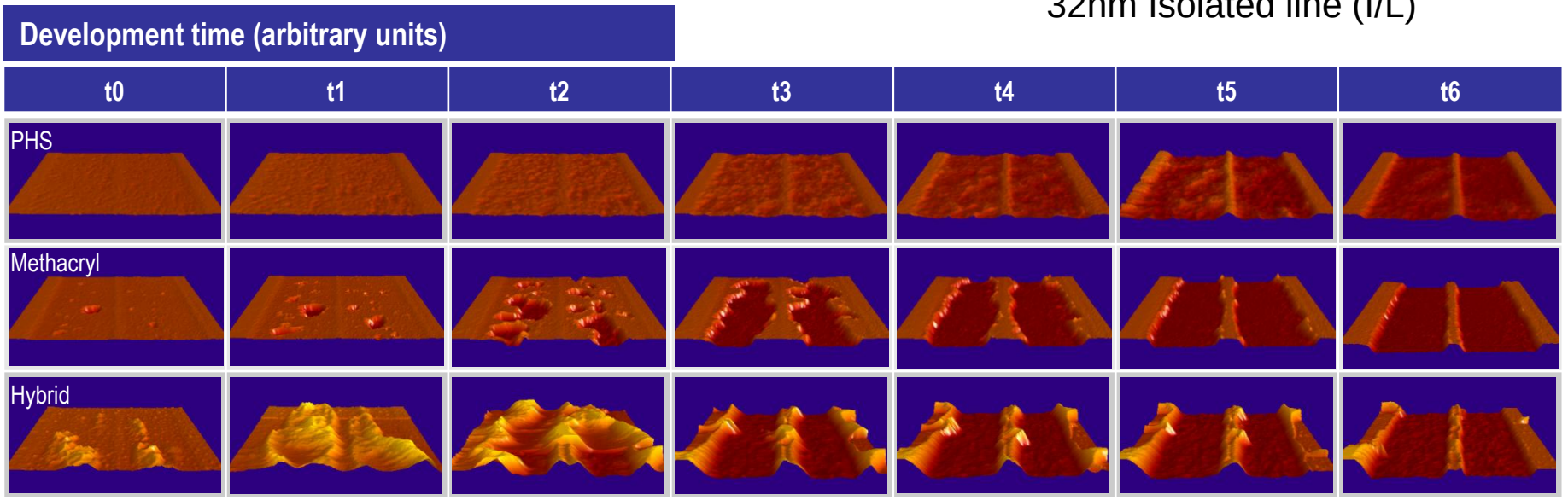
Dissolution process - analysis of dissolution characteristics

Evaluation conditions

Exposure tool : SFET（NA=0.3, Illumination=Ann.）
Resist : PHS based resist
Methacryl based resist
Hybrid based resist



32nm Isolated line (I/L)

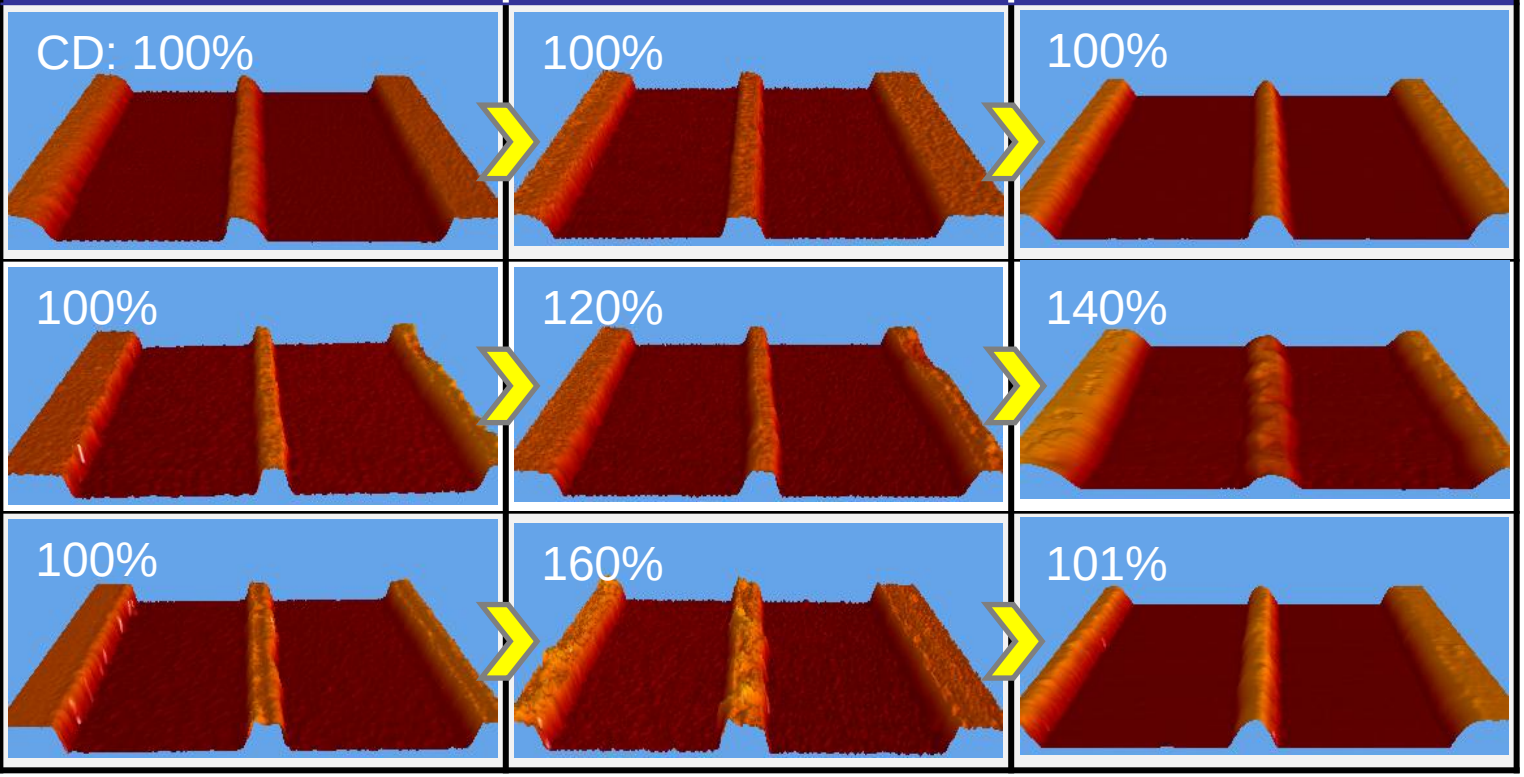


- PHS : Comparatively uniform and grain-like dissolution
- Methacryl : Crater-like dissolution
- Hybrid : Large swelling at exposed area

Rinse and Drying process – CD measurement & analysis

Pattern size: 32nm I/L

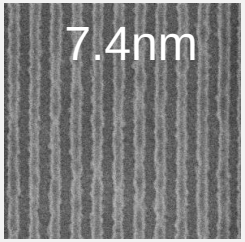
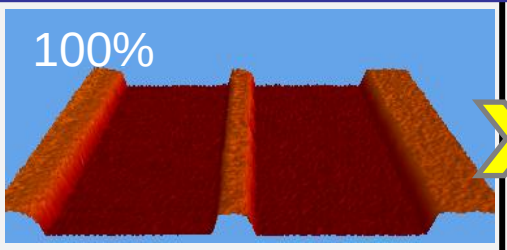
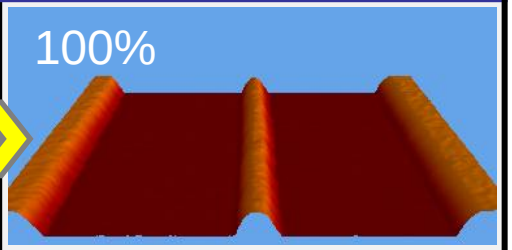
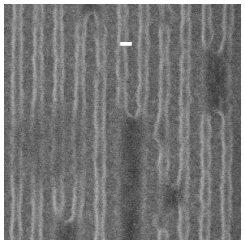
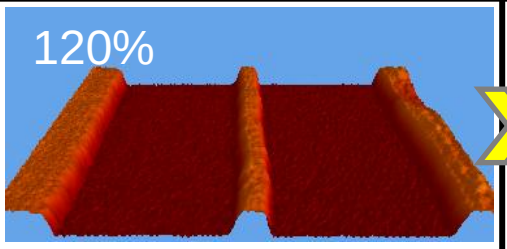
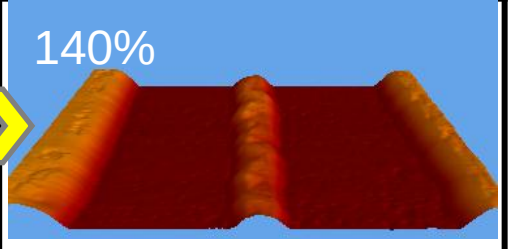
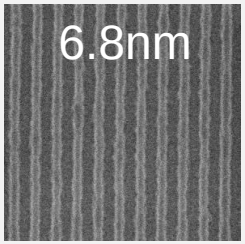
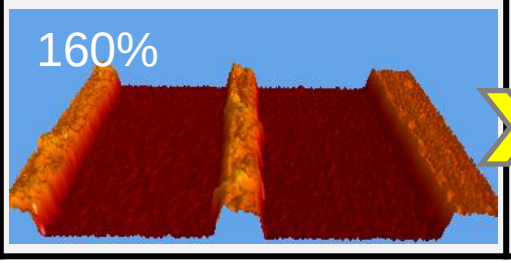
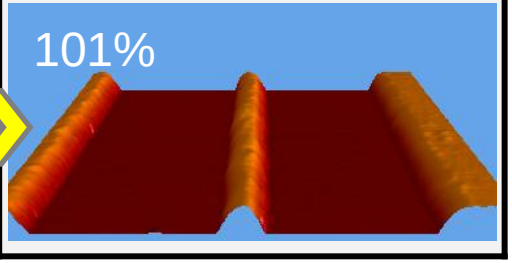
Resist	After dissolution	After rinse	After drying
PHS-based	CD: 100%	100%	100%
Methacryl-based	100%	120%	140%
Hybrid	100%	160%	101%



- PHS : No CD change during rinse.
- Methacryl : Remaining CD change after drying
- Hybrid : CD shrinkage after drying due to escape of water trapped during rinse.

Comparison between LWR and Rinse/Drying Behavior

Pattern size: 32nm I/L

Resist	LWR @30nm L/S	After rinse	After drying
PHS-based			
Methacryl-based			
Hybrid			

- HS-AFM analysis indicates that pattern swelling during rinse process may improve LWR.
- These results suggest that surfactant rinses showed the same effects during rinse process for LWR reduction of ESR1.

Summary

- EIDEC selected Standard Resist ESR1 with good balance of lithographic performances.
- 16 nm Line and Space pattern of chemically amplified resist was obtained by using X-dipole illumination of SFET.
- Surfactant rinse process was evaluated to reduce LWR and to suppress pattern collapse. The effect of surfactant rinse was considered.
- By using HS-AFM, dissolution behaviors of typical type of EUV resists were analyzed. LWR reduction due to swelling during rinse and shrinkage after drying was suggested.

Acknowledgements

- This work is supported by New Energy and Industrial Technology Development Organization (NEDO).

- We would also like to thank:

  EIDEC member companies for the continued support.
  Resist suppliers for supplying the materials.

END

Thank you for your attention!