2023 EUVL Workshop & Supplier Showcase /June 3-7, 2023

TEL

Advanced Resist Patterning Processes for High-NA EUV Lithography (P44, Invited)

June 6, 2023

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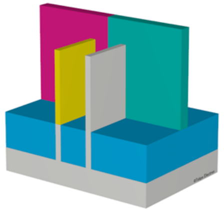
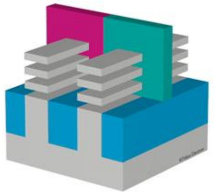
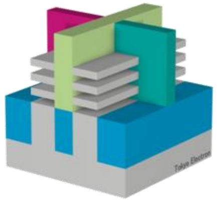
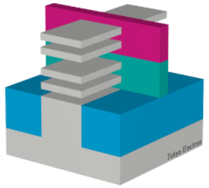
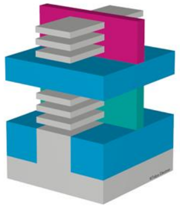
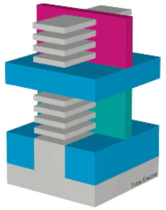
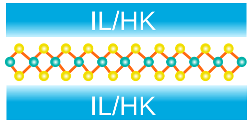
Contents

Wafer Resist Coater/Developer

Introduction: High NA EUV Lithography Patterning Requirements

EUV Lithography Technology Roadmap in Logic Devices

Source: TEL estimates

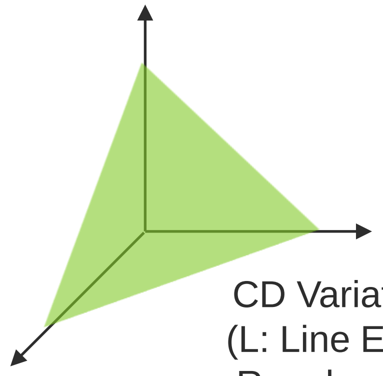
Year of HVM (20k/month)	2022~23	2024~2025	2027~28	2029	2031	2033	2035
Node	**3 nm**	**2 nm**	**14A**	**10A**	**7A**	**5A**	**3A**
Device	2~1 Fin 	GAA NS 	Forksheet 	CFET 	2nd Gen. CFET 	3rd Gen. CFET 	 2D material: TMDC MoS_2, WS_2, $MoSe_2$, WSe_2 etc.
Poly pitch (PP)	45	45	42	42	39	36	27
Min. Metal Pitch [nm]	22	20	18	16	12	12	12
EUV patterning technology	EUV MP	EUV MP	EUV MP **High NA EUV**	EUV MP **High NA EUV MP**	EUV MP **High NA EUV MP**	EUV MP **High NA EUV MP**	EUV MP **High NA EUV MP**
Resist	**CAR**	**CAR (+MOR)**	**CAR (+MOR)**	**CAR+MOR**	**CAR+MOR**	**CAR+MOR**	**CAR+MOR**

CAR: Chemically Amplified Resist, MOR: Metal Oxide Resist, MP: Multi-patterning

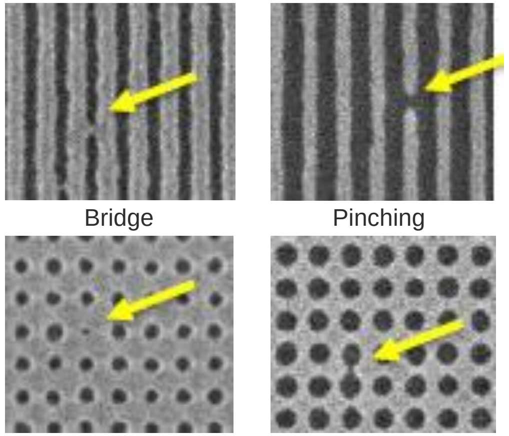
With progress in technology nodes, minimum feature size reduction continues.
Today in this talk, high-NA EUV lithography related process technologies will be highlighted

Challenges in High NA EUV Lithography Processes

RLS trade off

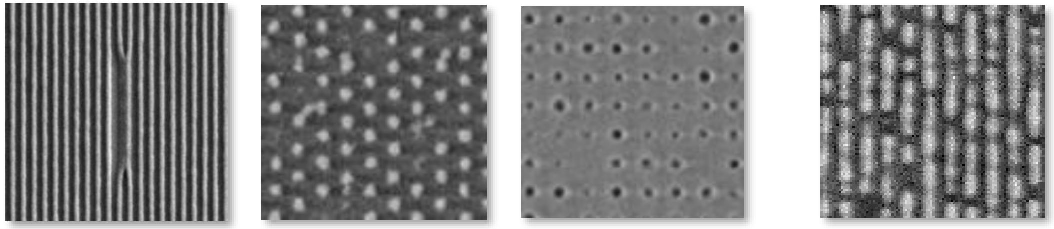


Stochastic defects



P. De Bisschop, Proc. SPIE, 10957-10 (2019)

Issues in securing required resist film thickness



Resist line collapse

Resist pillar collapse

Scums

Post-etch resist damage (Pinching)

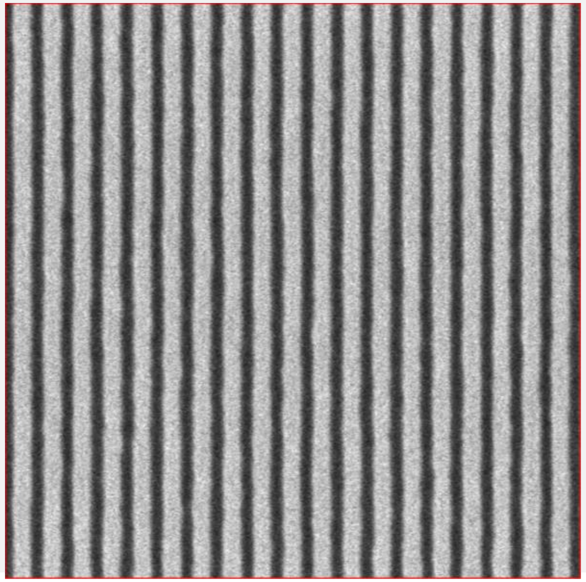
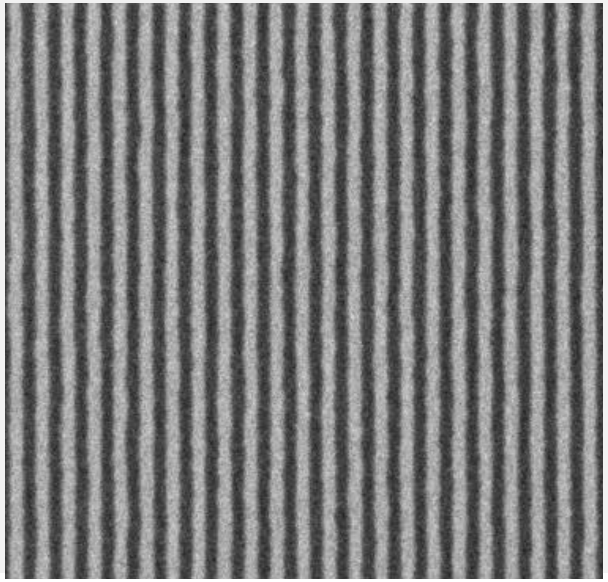
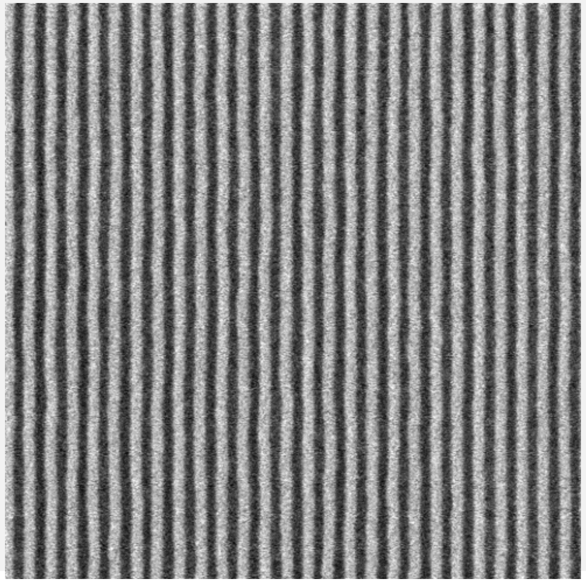
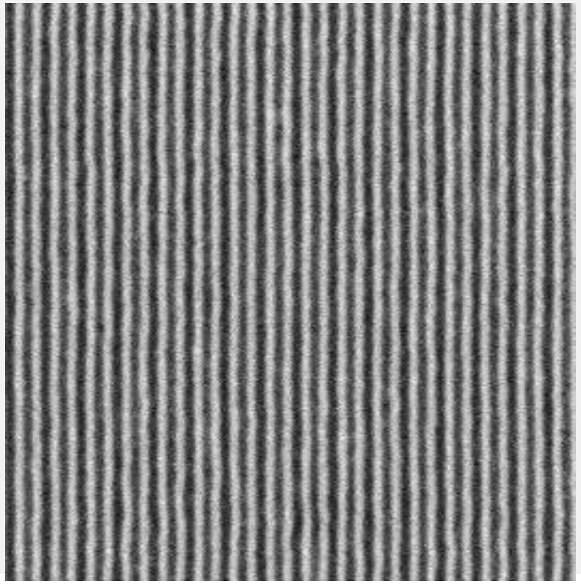
Challenges for Thickening Resist Film

Challenges for Thinning Resist Film

Resist sensitization and roughness reduction are the keys for reducing CoO of EUV lithography process
Reduction of stochastic defects and reducing resist pattern collapse/ scums and post etch pinching are important challenges for high NA EUV fine patterning

EUV Patterning Performance by NA0.33 EUV Lithography

SE: Single Exposure /MP: Multi Patterning

EUV SE 30 nm P	EUV SE 24 nm P	EUV MP 20 nm P	EUV MP 14 nm P
			
CD 16.0 nm LER 1.40 nm	CD: 12.1 nm LER: 1.56 nm	CD: 10.0 nm LER: 1.70 nm	CD: 7.1 nm LER: 1.36 nm

Source: TEL

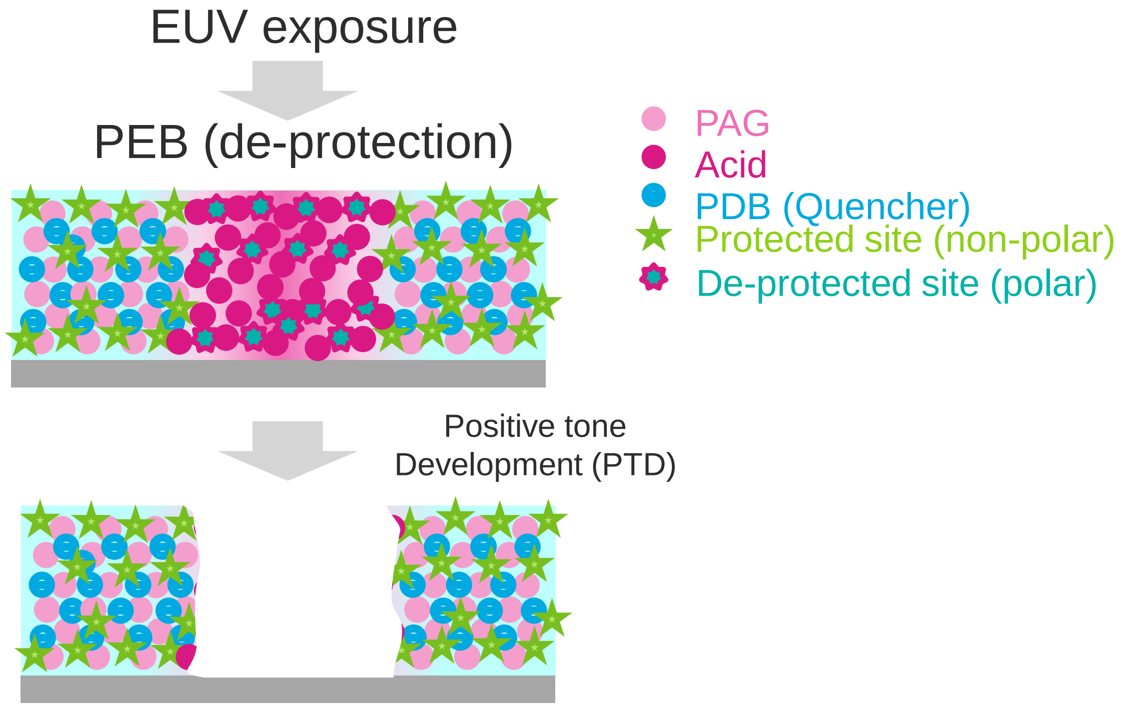
TEL is actively working on advancement in scaling for high NA EUV lithography.
In this talk we will update the improvements in results focusing on single patterning extension

Patterning Innovation by New Development Method (ESPERT™)

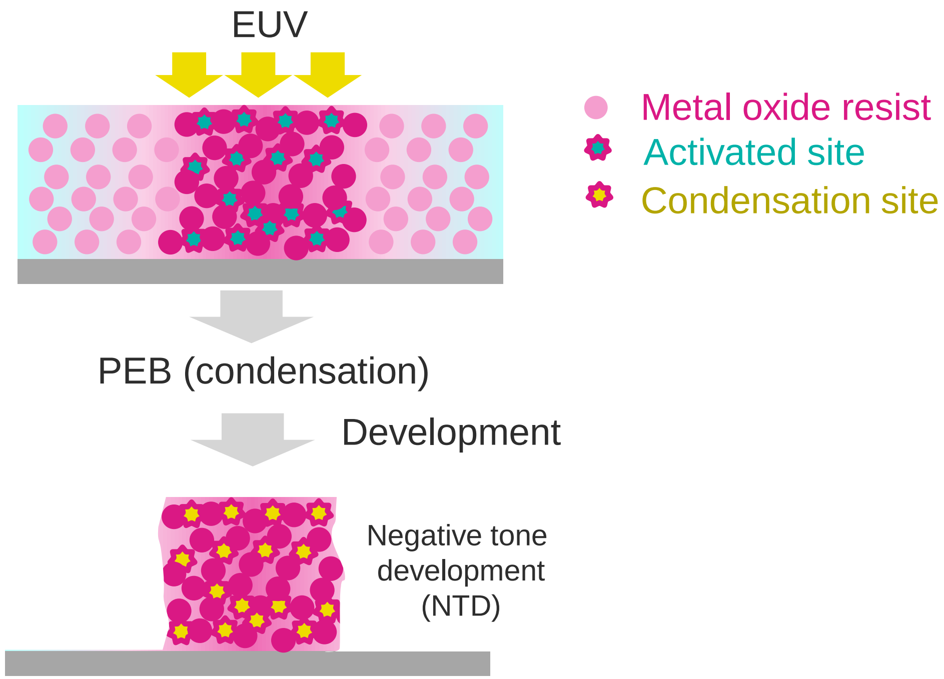
Resist Types for High NA EUV Lithography

Next topic

Chemically Amplified Resists (CAR)



Metal Oxide Resists (MOR)

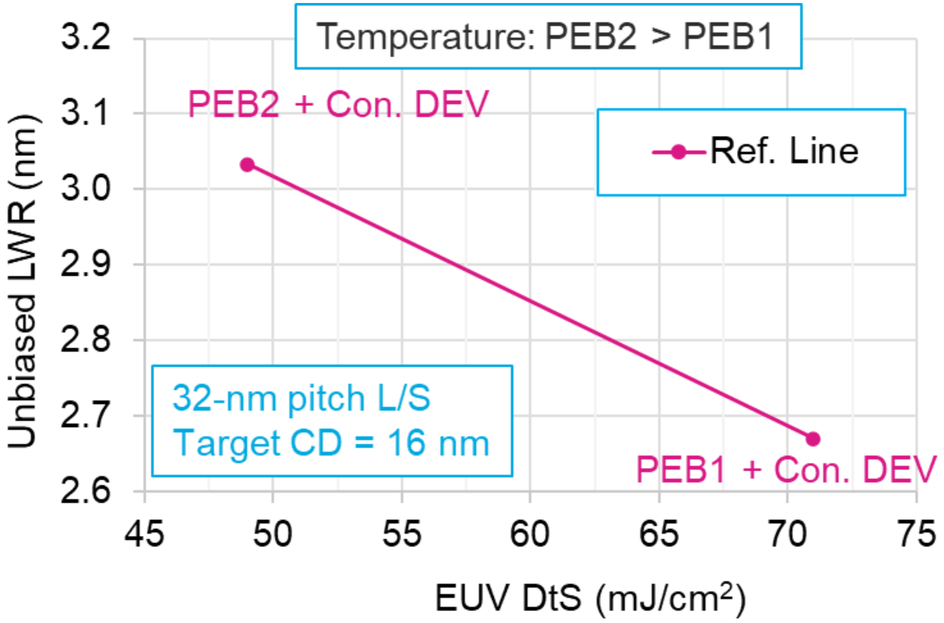


CAR: Established current main stream resist, metal-free
MOR: High EUV absorption, less image blur for improved RLS

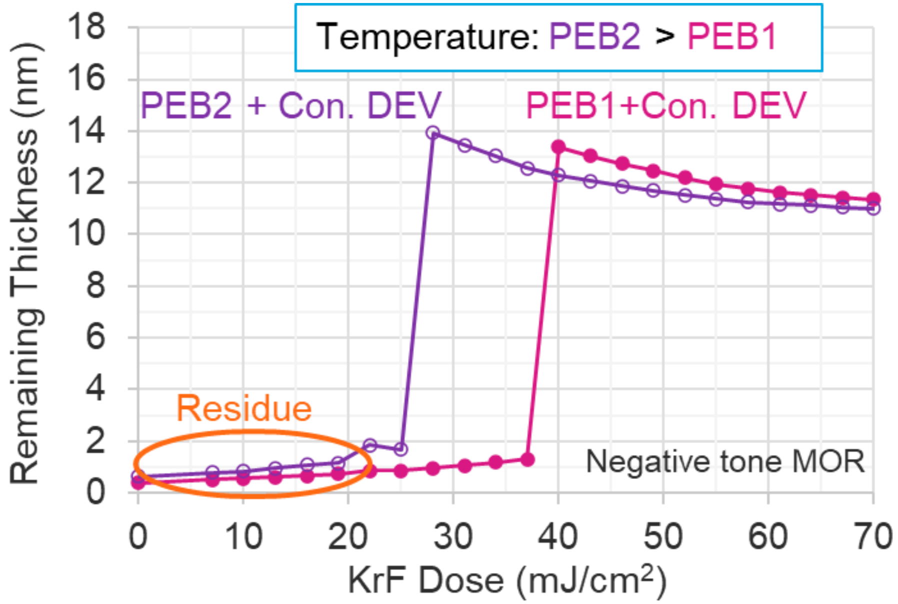
Challenge: Dose-Roughness/Residue Trade-off Relationship for MOR

Dinh, et al., SPIE ALP2023

Roughness-Sensitivity



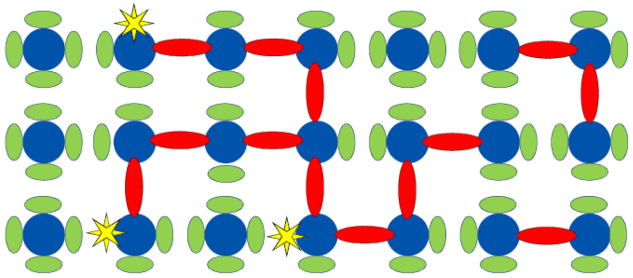
Contrast Curves



Higher PEB temperature: Higher resist sensitivity, but higher roughness and more scums
Lower PEB temperature: Lower resist sensitivity, with better roughness and less scums

RLS Improvement by Stochastics Understanding in MOR

Dinh, et al., SPIE ALP2023



The standard deviation of the edge positions σ_{LER}:

$$\sigma_{LER} = \frac{\sigma_m}{dm/dx} + \sigma_0$$

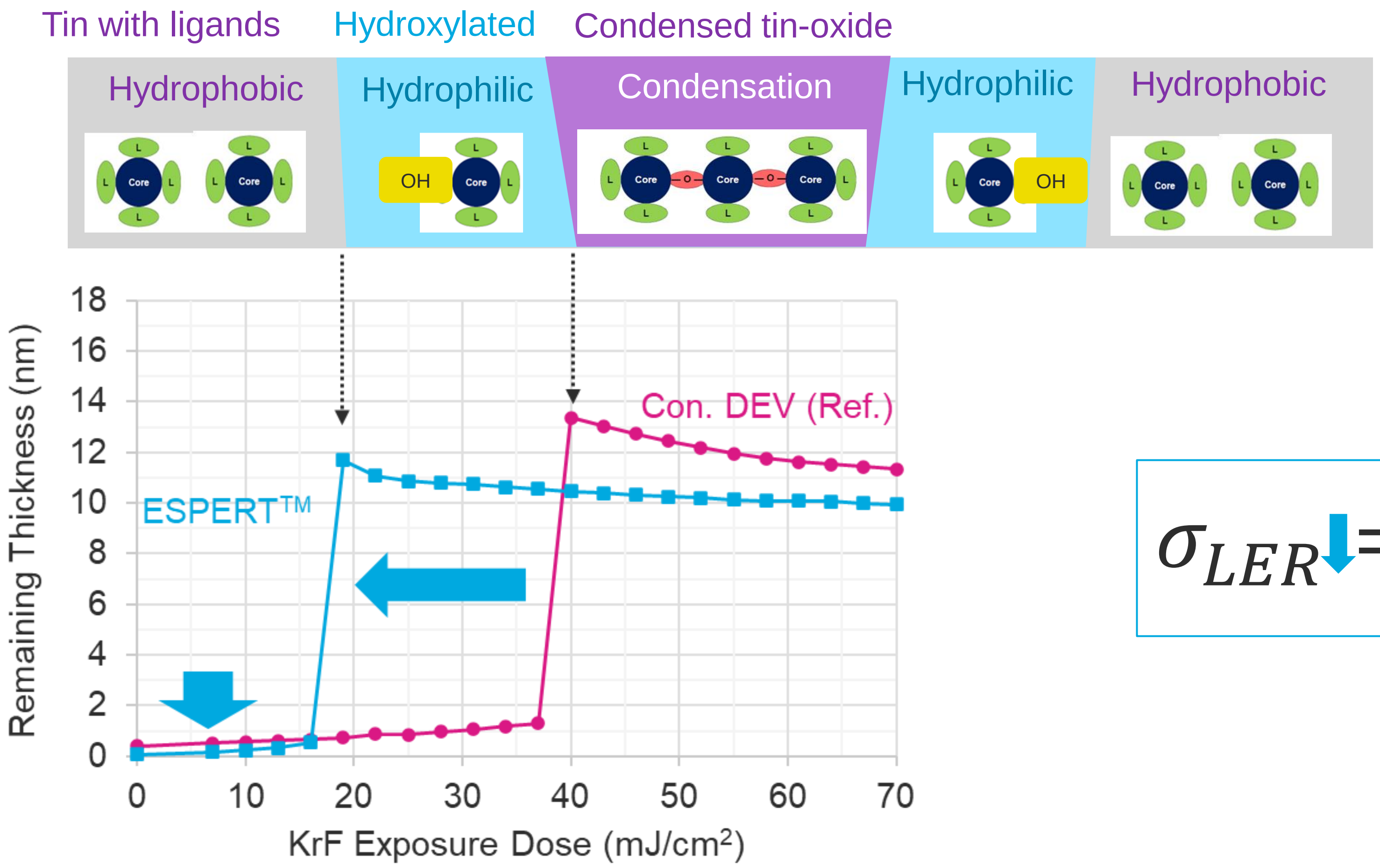
Derived from the simple model of line-edge roughness for CAR, C. Mack, Future Fab International, Vol. 34 (2010)

- σ_m: The standard deviation in concentration of resist dissolution inhibition (polarity change/Mw change)
- *dm/dx*: The gradient of resist dissolution inhibition
- σ_0: The standard deviation due to finite size of the condensed molecule at the edge

To have a lower CD variation (σ_{LER}), it is necessary to:

- reduce σ_m (Mainly chemical stochastics)
- increase *dm/dx* (Chemical contrast, descum)
- reduce σ_0 (Molecular size)

Solution: Enhanced Sensitivity develoPER Technology, ESPERT™ for Improved RLS



Dinh, et al., SPIE ALP2023

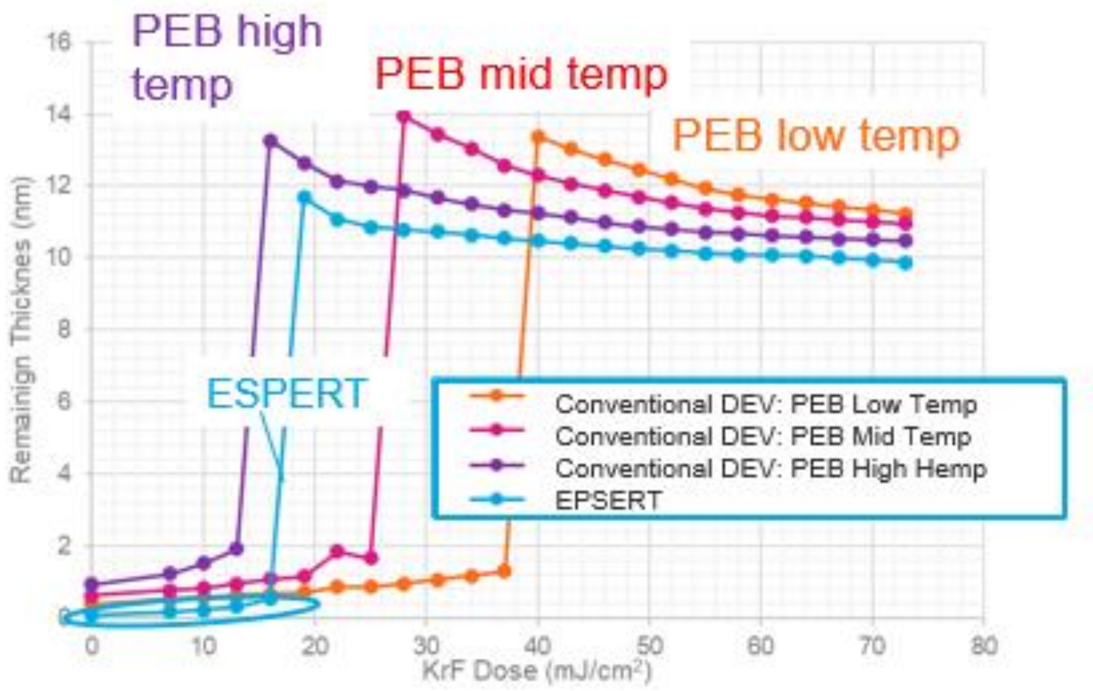
$$\sigma_{LER}\downarrow = \frac{\sigma_m \downarrow}{dm/dx \uparrow} + \sigma_0 \downarrow$$

Solubility contrast by Dev.

ESPERT™ develops MOR by the outer edge of polarity switching → Lowers σ_m , σ_0
ESPERT™ can remove the scums effectively at lower exposure dose area → Increases *dm/dx*

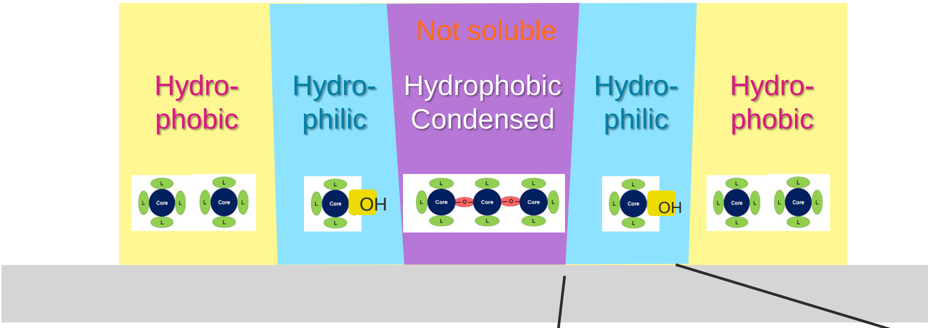
The Advantages of ESPERT™ vs. Conventional Development

Dinh, et al., SPIE ALP2023



ESPERT™ gives higher sensitivity combined with higher scum removal leading to a higher development contrast for better roughness

Resist Roughness and Sensitivity Improvement by ESPERT™

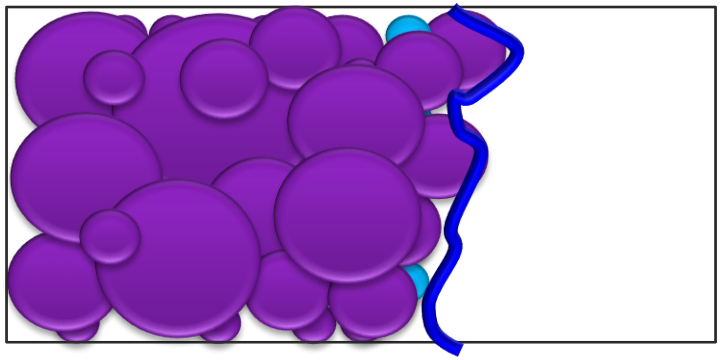


Unexposed：with hydrophobic ligand

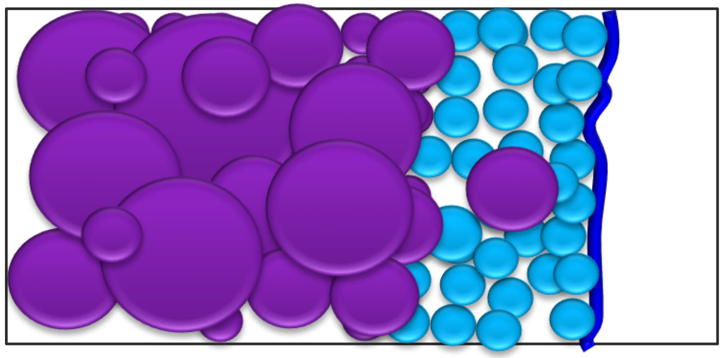
Exposed：-OH (hydrophilic)

Exposed：Condensation

DEV with molecular size



DEV with polarity switch

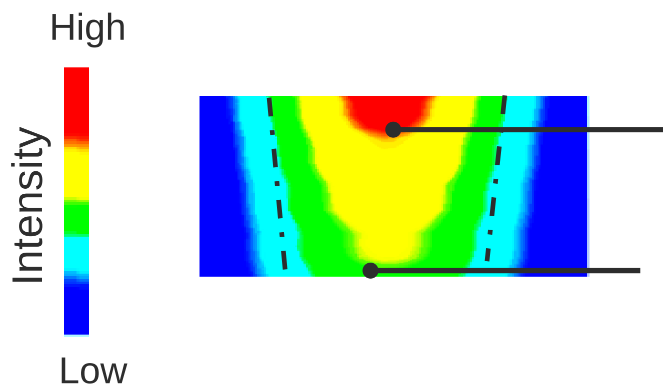


Roughness becomes worse due to larger cluster size

Roughness becomes better due to smaller cluster size

Resist Profile Advantage by ESPERT™ *Enhanced Sensitivity developer Technology™*

Latent image in a MOR

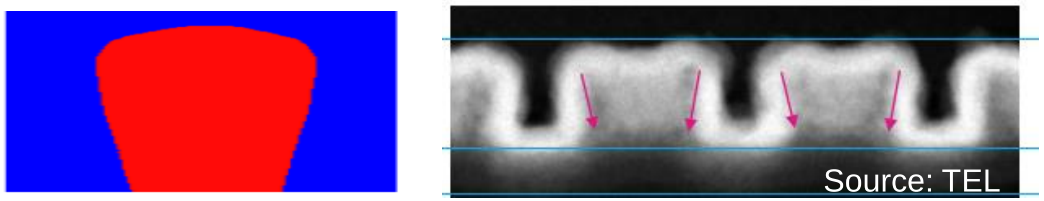


Higher photon absorption surface area

Lower photon absorption bottom area

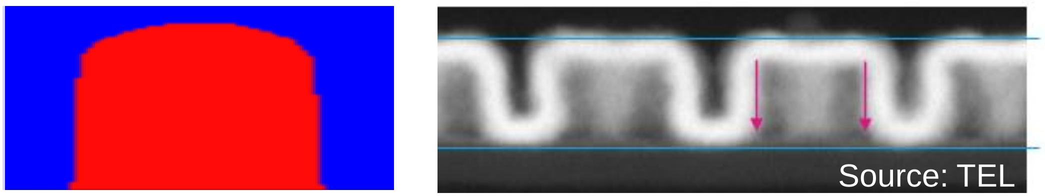
ESPERT™
- ✓ Improved sensitivity
- ✓ Improved LWR
- ✓ Improved pattern profile
- ✓ Improved pattern collapse margin

Conventional Process (Condensation edge)



Reverse tapered shape

ESPERT™ (Polarity switch edge)



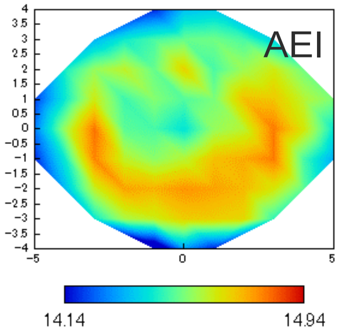
Vertical shape

Pitch 32 nm L/S ESPERT™ Breaks Dose-Defect Trade-off (NA0.33)

AEI CDU

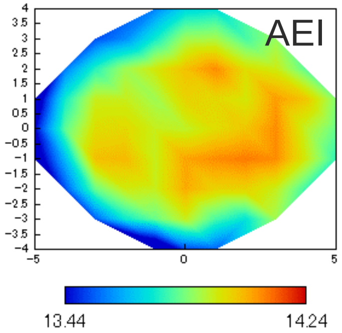
*AEI: After etch inspection

Conventional wet development



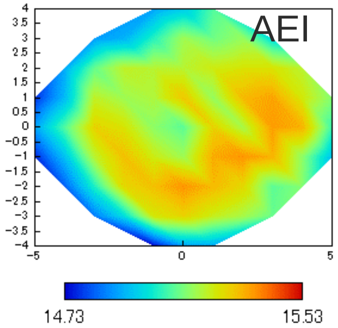
Dose = **44.2** mJ/cm^2
CD = 15.2 nm
LWR = 1.99 nm
CDU 3σ: **0.52** nm

ESPERT™ (condition-1)



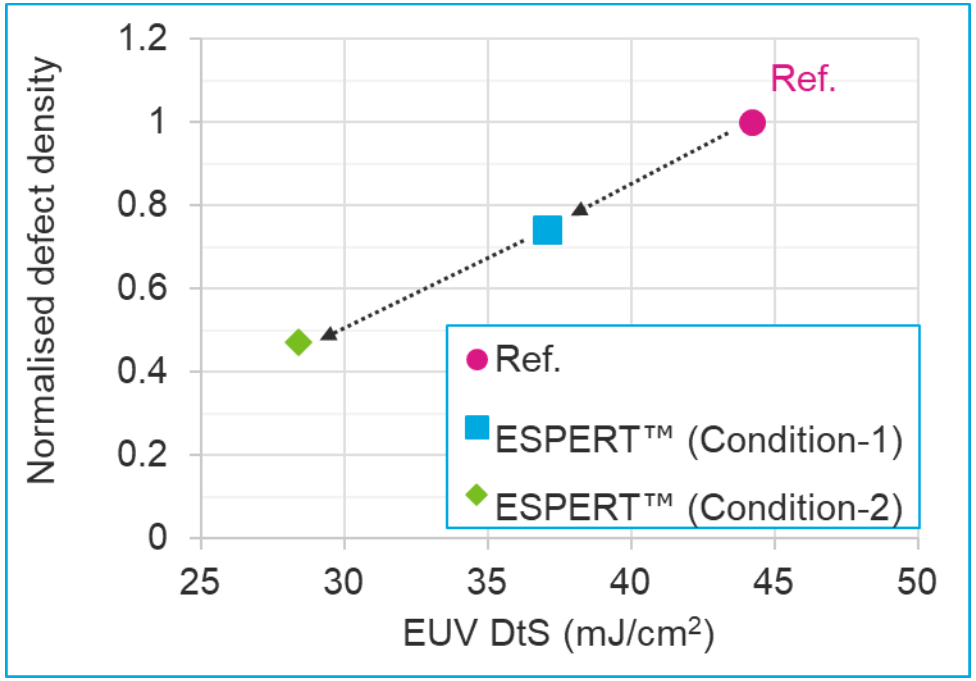
Dose = **37.1** mJ/cm^2
CD = 14.9 nm
LWR = 2.06 nm
CDU 3σ: **0.55** nm

ESPERT™ (condition-2)



Dose = **28.4** mJ/cm^2
CD = 15.2 nm
LWR = 2.15 nm
CDU 3σ: **0.38** nm

AEI single-bridge defects (KLA inspection with full wafer)

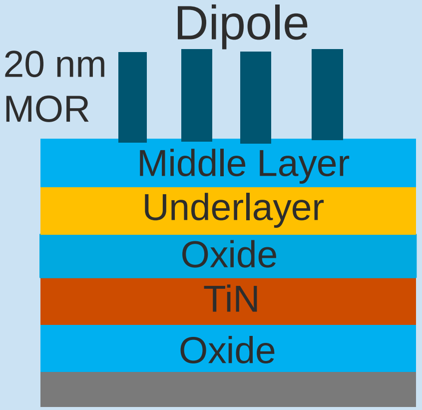
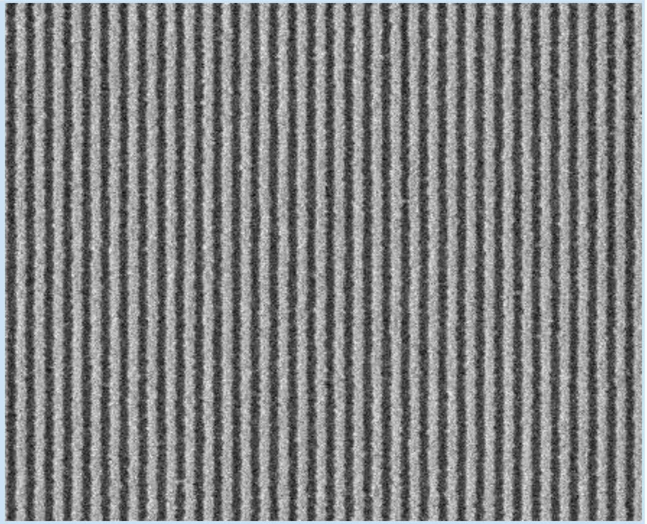
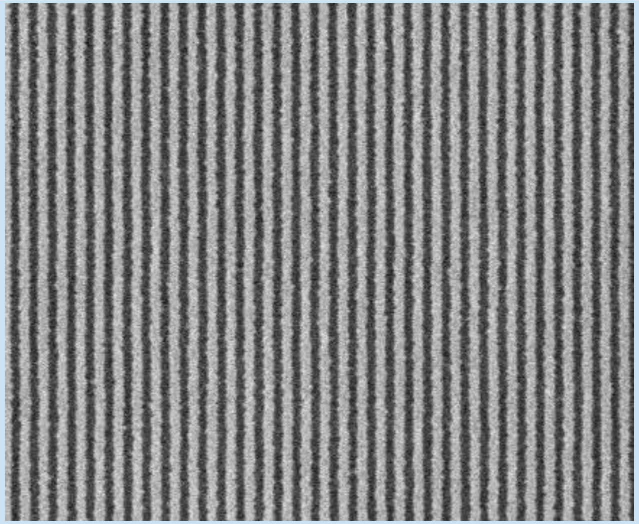
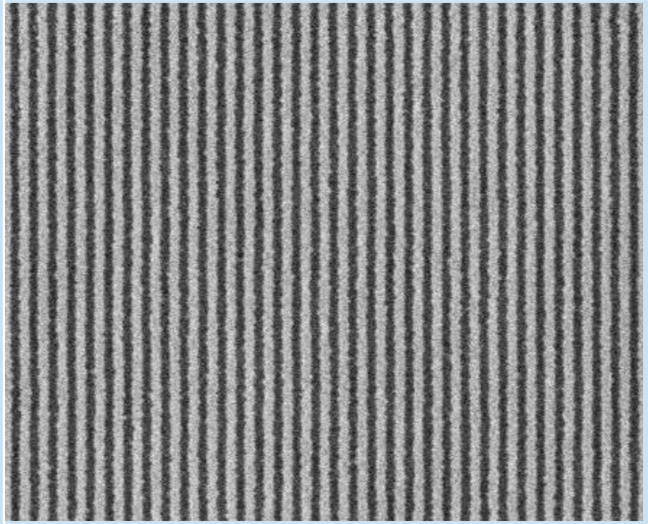


Inspection area: 98.4234 cm^2

ESPERT™ Condition-2 improved the EUV sensitivity about 36% (from 44.2 mJ/cm^2 to 28.4 mJ/cm^2), while single-bridge defects was reduced by a factor of 2.1 and global CDU is improved.

Pitch 24 nm ADI L/S Performance Using ESPERT™ (NA0.33)

*ADI: After development inspection

ADI P24LS 1:1	Conventional wet dev	ESPERT™ Condition 3	ESPERT™ Condition 4
Top-down SEM 			
Dose (mJ/cm²)	54	39	38
uLWR/LER (nm)	3 / 2.3	3.2 /2.4	3.2 /2.4
FFL* (nm)	2 nm (CD10 - 12 nm)	2.7 nm (CD 10-12.7 nm)	3 nm (CD 10.0-13.0 nm)
Smallest CD (nm)	9.4	9.0	9.6

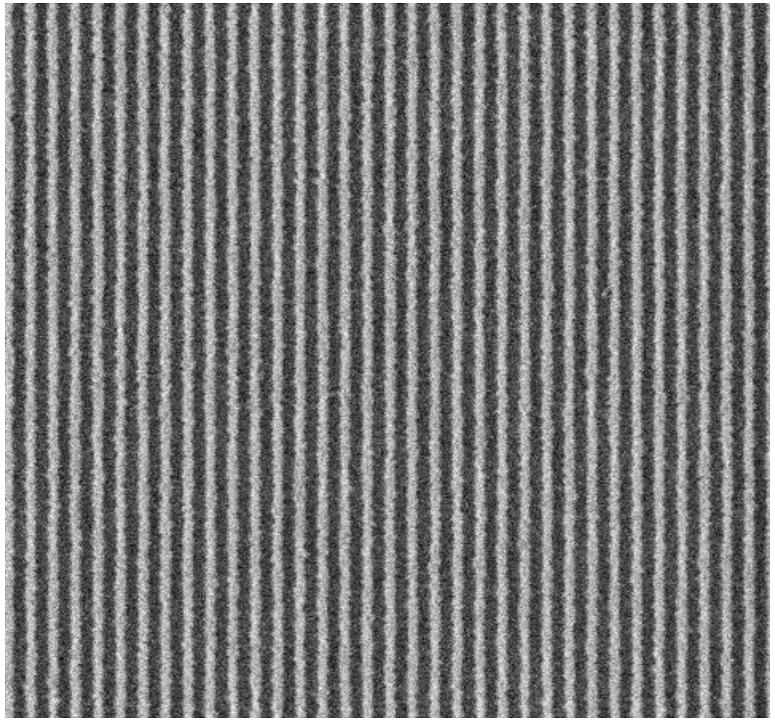
*FFL: Failure Free Latitude by SEM images

30% dose reduction with ESPERT™ obtained at comparable LER

ADI failure free latitude can be improved by ESPERT™ thanks to better scum removal

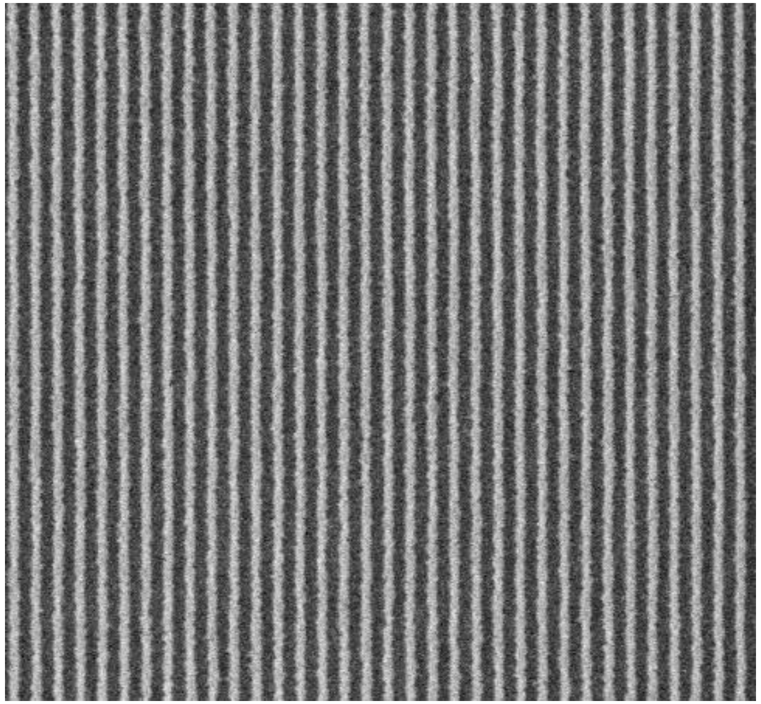
Pitch 24 nm ADI L/S Pattern Collapse Prevention Using ESPERT™ (NA0.33)

Conventional Wet Dev.



Min CD = 9.4nm

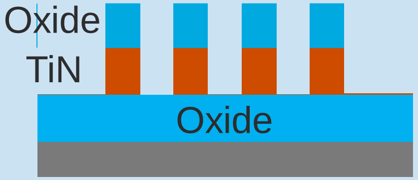
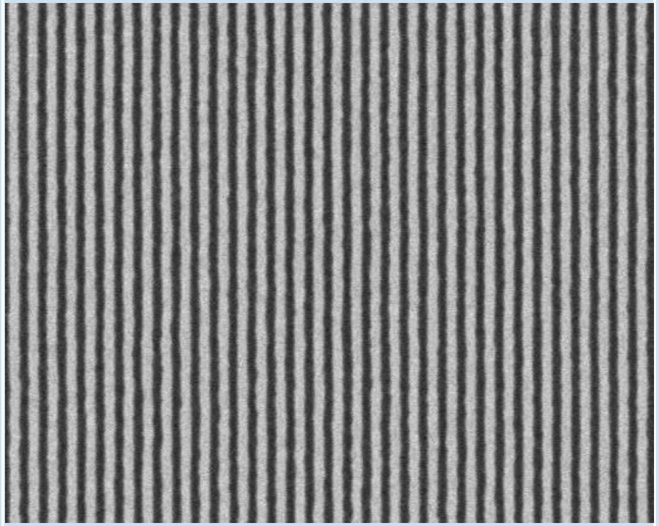
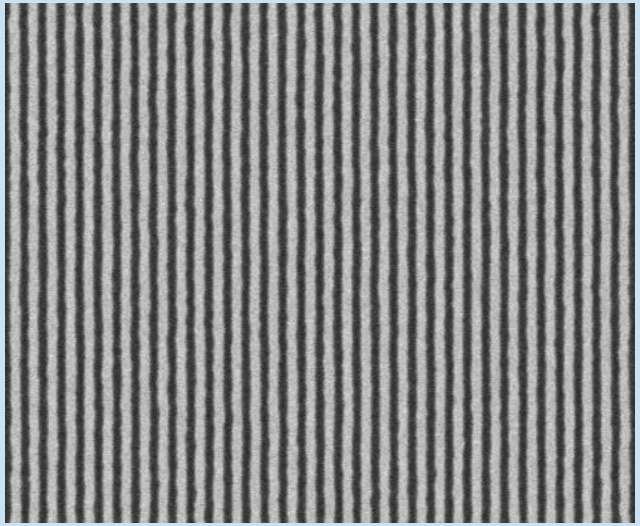
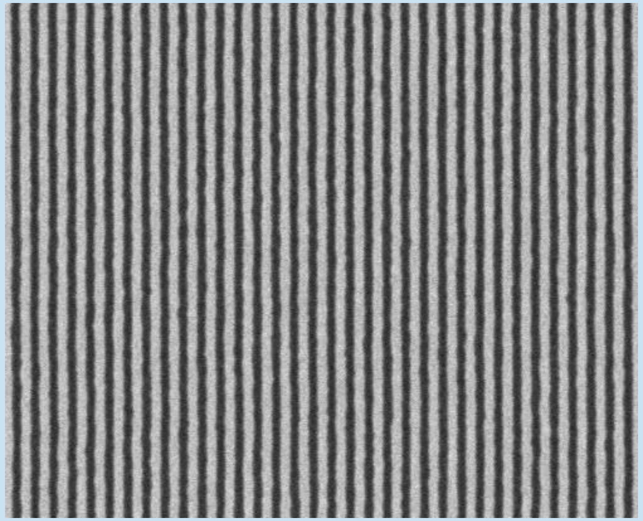
ESPERT™ Condition 3



Min CD = 9.0 nm

ESPERT™ has reasonable pattern collapse margin till 9 nm for target CD of 12 nm

Pitch 24 nm AEI L/S Performance Using ESPERT™ (NA0.33)

AEI P24LS 1:1	Conventional wet dev	ESPERT™ Condition 3	ESPERT™ Condition 4
Top-down SEM 			
Dose (mJ/cm²)	53	41	42.5
uLWR/LER (nm)	2.1 / 1.6	2.0 / 1.6	2.0 / 1.6
FFL* (nm)	2 nm (CD10 - 12 nm)	3.4 (CD 11.4-13.8 nm)	>3.8 (CD 11-14.8 nm)

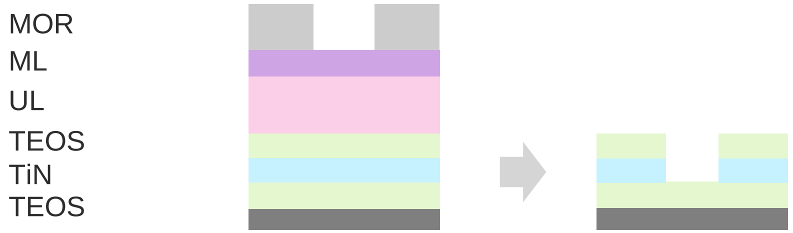
*FFL: Failure Free Latitude by SEM images

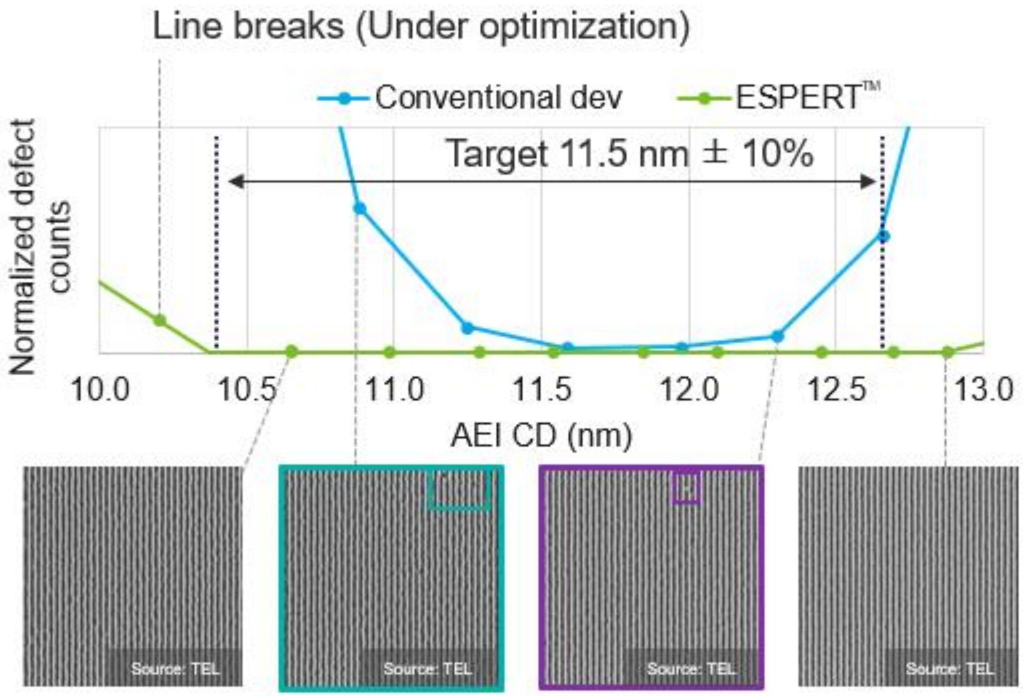
~20% dose reduction at AEI with ESPERT™ obtained at comparable LER
ADI failure free latitude can be improved by ESPERT™ thanks to better scum removal

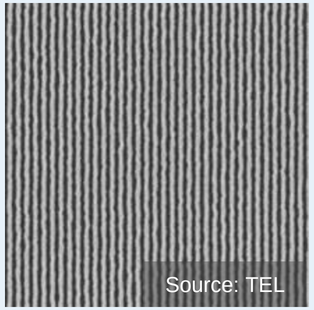
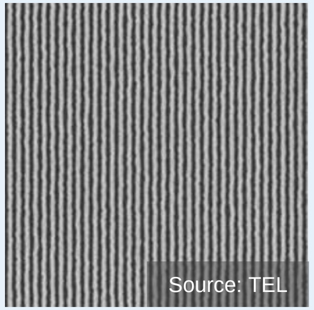
ESPERT™ AEI Performance at L/S 23 nm Pitch (NA0.33)

*AEI = After Etching Inspection

- Experimental conditions
  - Patterns: 23 nm pitch 1:1 LS
  - Inspection step: AEI (Under optimization)



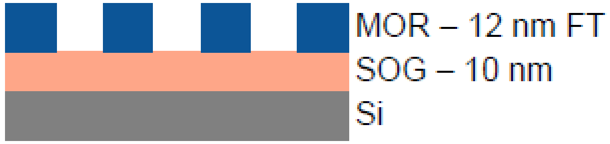


		Conventional dev	ESPERT™
EUV dose (mJ/cm^2)		69.0	65.0
AEI	SEM image		
	CD (nm)	11.5	11.5
	Unbiased LWR (nm)	2.36	2.20
	Unbiased LER (nm)	2.48	2.25

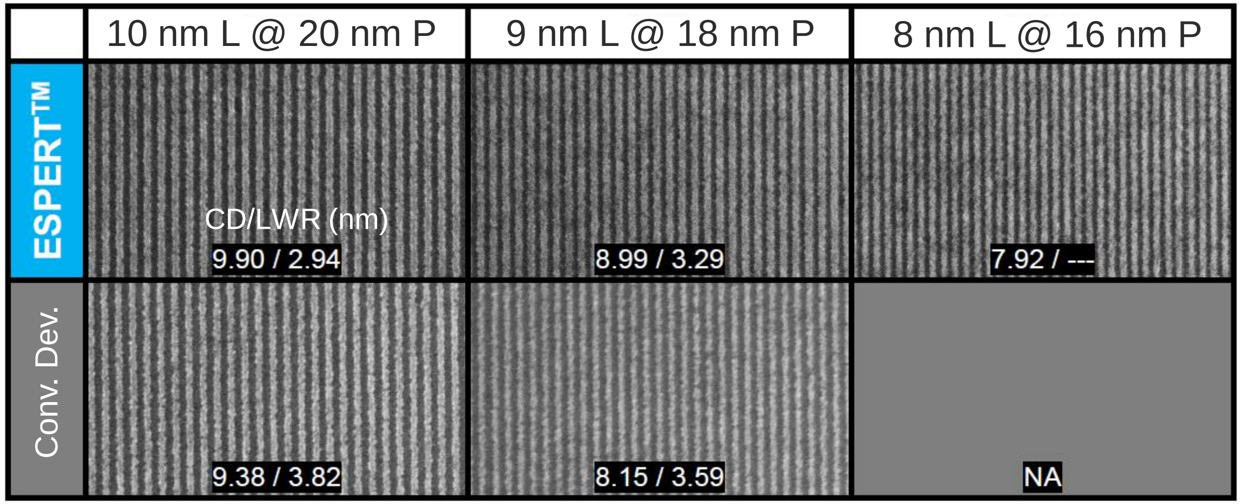
ESPERT™ improved DtS, roughness and defect cliff at AEI L/S 23 nm pitch

High-NA Exposure: Pitch 20~16 nm L/S by ESPERT™ (BMET NA0.5)

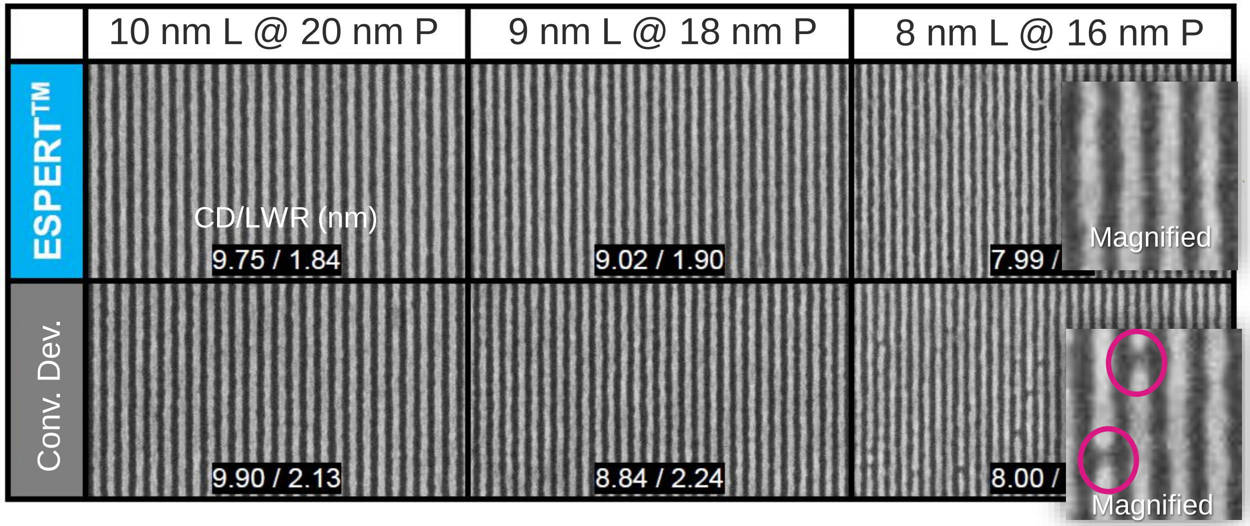
Meyers, inpria SPIE2023 paper



ADI After Development Inspection



AEI After Etch Inspection



ESPERT™ Dose ~65 mJ/cm²
POR Reference Dose 88 mJ/cm²

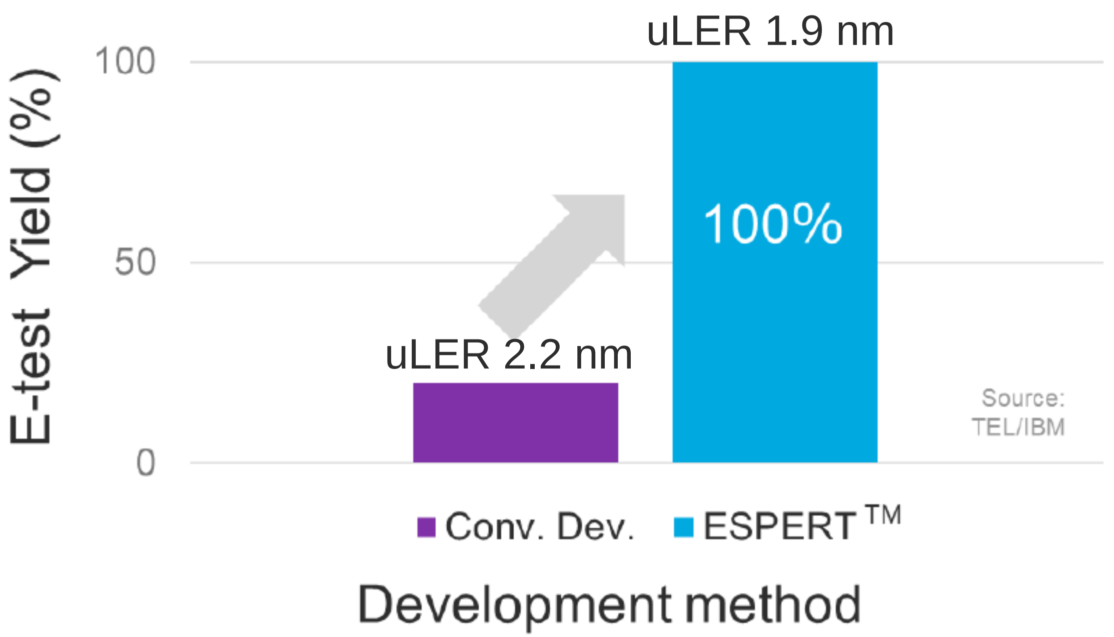
ESPERT AEI LWR 1.8~1.9 nm
POR Reference Dev. 2.1~2.3 nm

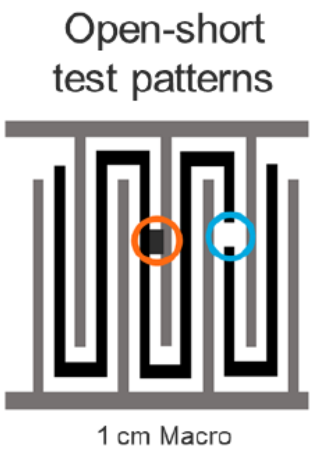
ESPERT™ reduces dose by ~24% and LWR by 15~20% lower for fine pitch patterns

Electrical Yield Study for 28 nm L/S Patterns

Huli, et al., SPIE ALP2023

28 nm Pitch L/S Open Short Pattern E-Test Yield





Electrical Yield significant increase with ESPERT^{TM} process was observed with 10% dose reduction compared to reference wet process

Summary

Summary

- For high NA EUV generation, patterning challenges become more and more significant
- New development method called ESPERT™ was confirmed to be effective for improving Metal Oxide Resist (MOR) fine patterning performance by
  – Improved RLS (high resolution, better roughness, better EUV sensitivity)
  – less defects (less pattern collapse, less pinching, less bridges with less scums)
  – better resist profile
  – better global CDU
- The advantage of ESPERT is explained by showing improved resist dissolution contrast and chemical stochastics reduction model by selecting proper development interface

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