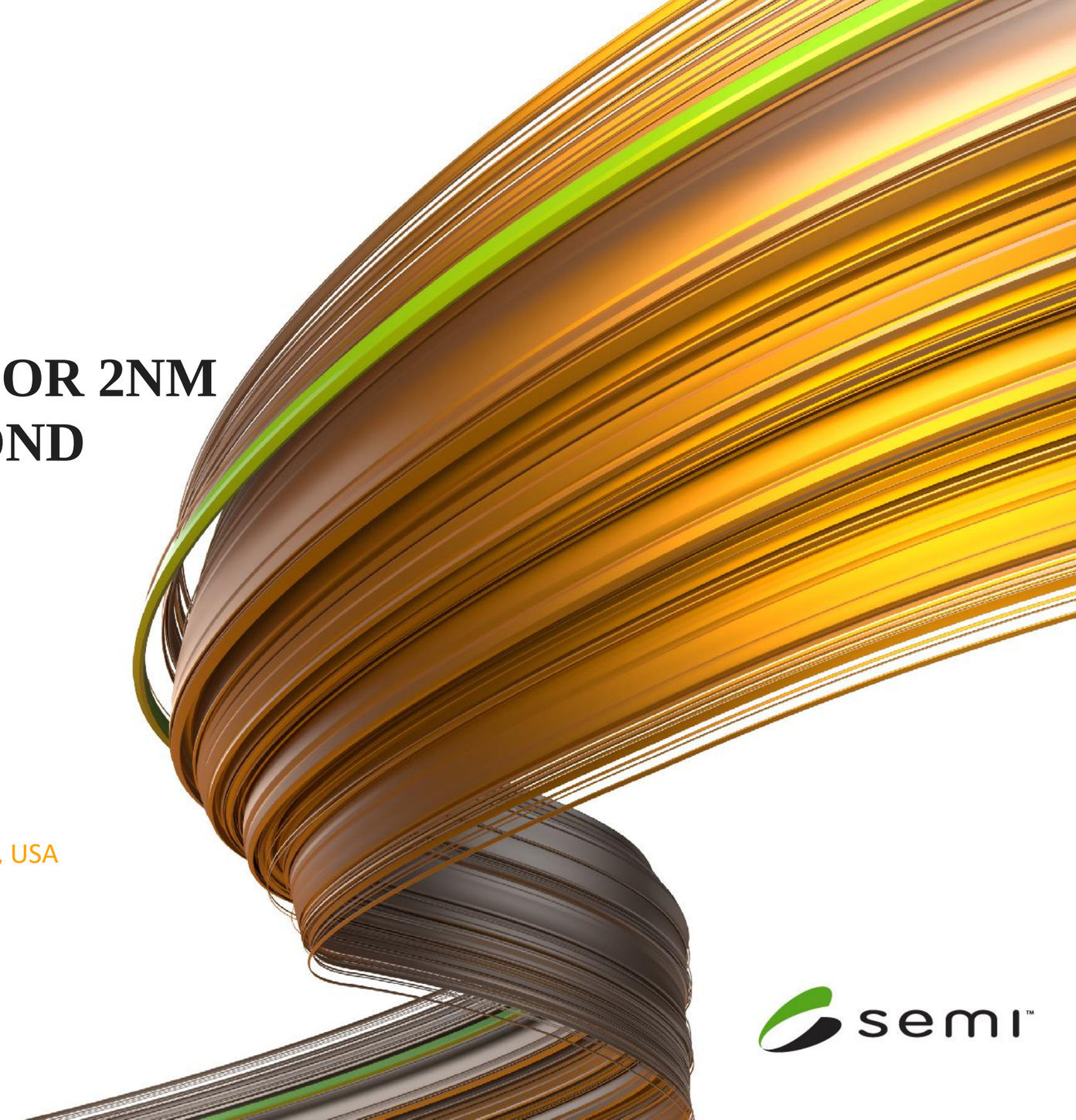
SEMICON® WEST

BUILDING A PATH FORWARD

EUV DRY RESIST & PROCESS FOR 2NM NODE PATTERNING AND BEYOND



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#SEMICONWest

semi™

OUTLINE

INTRODUCTION

DRY RESIST EQUIPMENT AND PROCESS FLOW

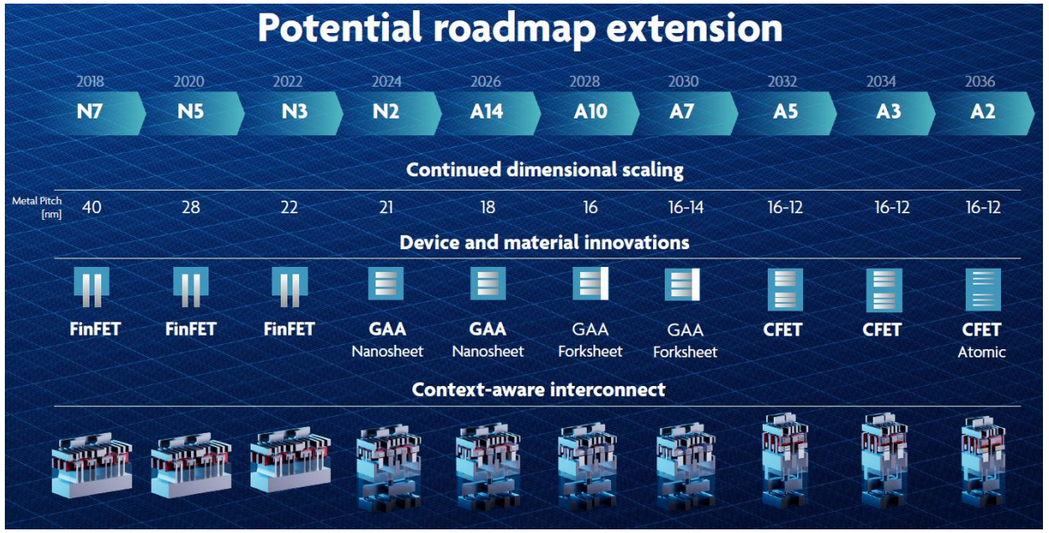
ON-WAFER PERFORMANCE

HOLISTIC PROCESS BENEFITS

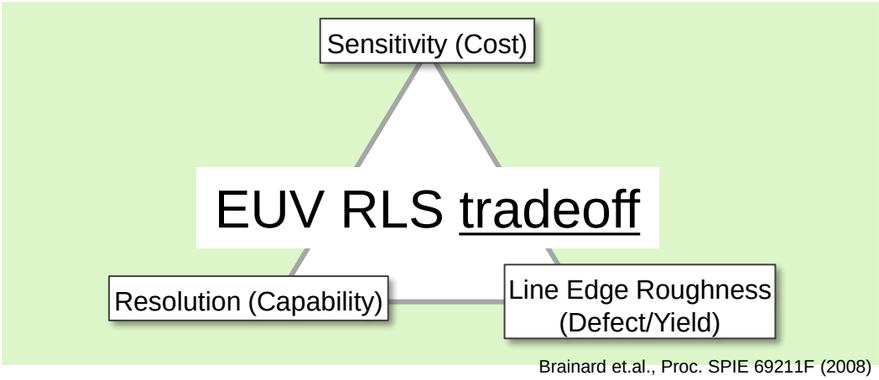
SUMMARY

EUV LITHOGRAPHY INFRASTRUCTURE ENABLING CONTINUED SCALING

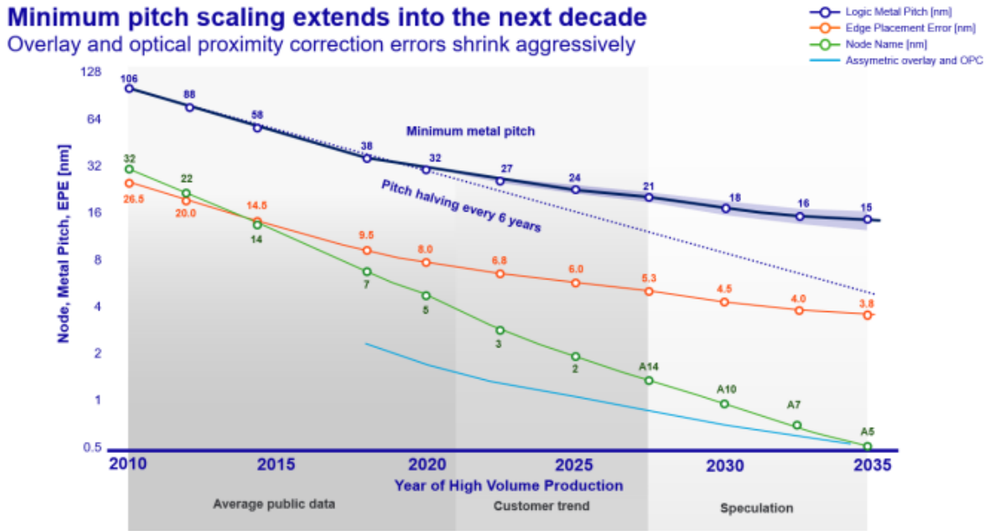
WORKING TO SOLVE REMAINING RESIST CHALLENGES



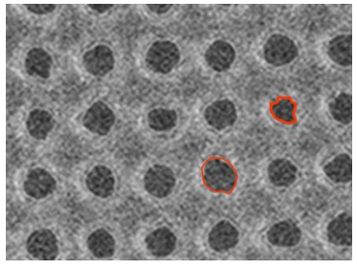
Source: Luc Van den hove, imec, SPIE 2022 / ISS 2022



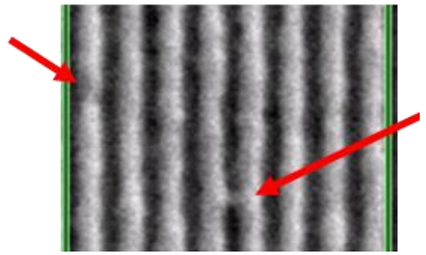
Brainard et.al., Proc. SPIE 69211F (2008)



Stochastic effects present challenges to optimizing EUV resist resolution, line edge roughness, and sensitivity simultaneously.



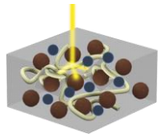
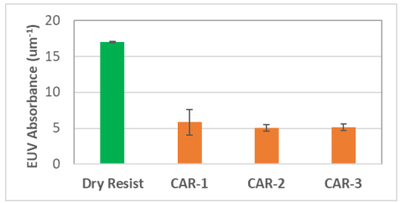
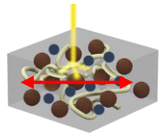
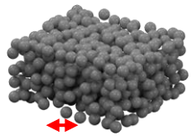
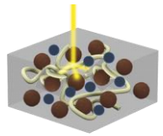
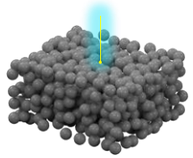
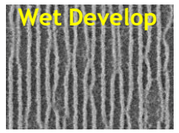
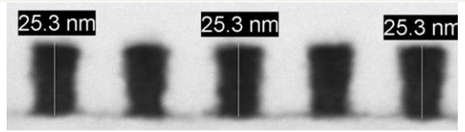
Via patterns in resist



Line/space patterns in resist

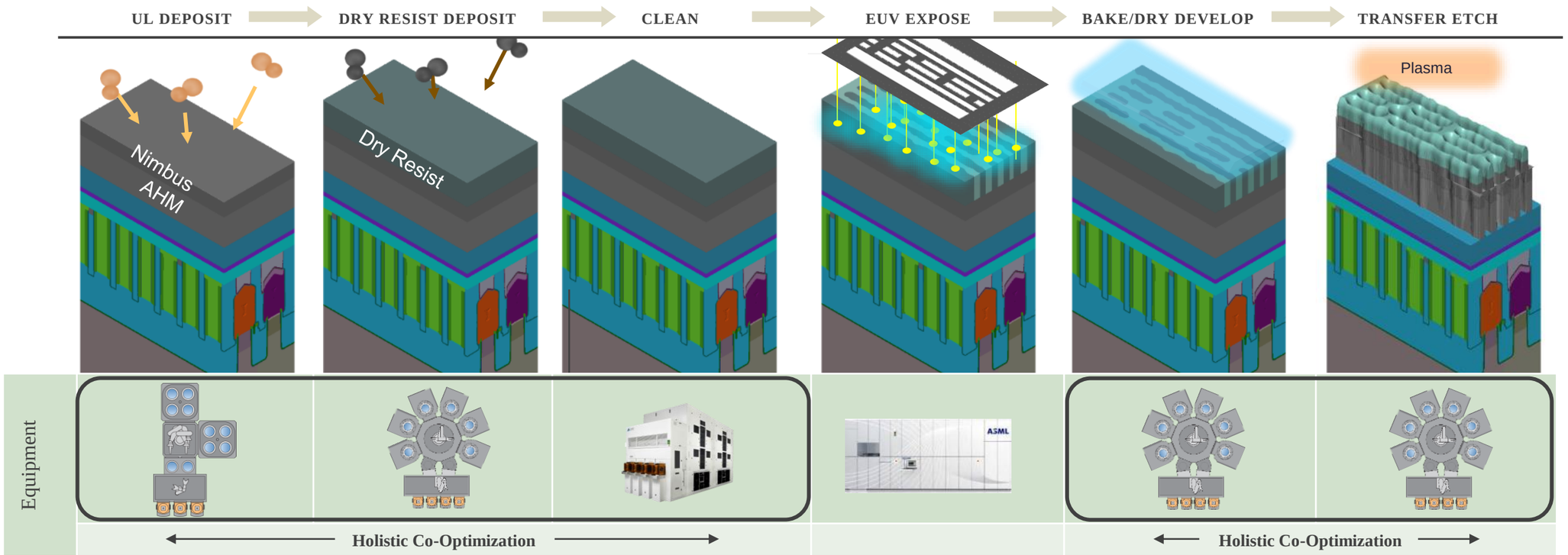
DRY EUV RESIST SUPERIORITY OVER ORGANIC CAR

FOR PITCH ≤ 32NM, HIGH-FIDELITY, LOW-DEFECT PATTERNING, AND A GREEN SOLUTION FOR THE FAB

	Organic CAR	Dry EUV Resist
EUV Absorption	 Organic hydrocarbons Weaker EUV absorption	Organometallics >3X better EUV absorption 
Basic Unit Size	 Large molecules (~16Å)	~6X smaller molecules (~2.5A) 
Chemical Stochastics	 Multiple components: Polymer + PAG + Base	Single component: Homogeneous, monodisperse 
Pattern Collapse	 High surface tension with wet development	No pattern collapse with dry development  High aspect ratio pillar patterns
Material Usage	 Excess dispense waste Excessive purge volumes Multi-step EUV	5-10x reduction in material waste, cost Process step consolidation saves power, CO2 and water 

CAR=Chemically Amplified Resist, PAG=Photoacid Generator, LWR=Linewidth Roughness

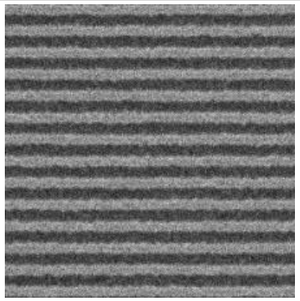
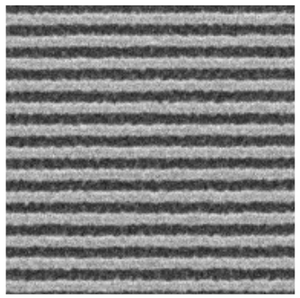
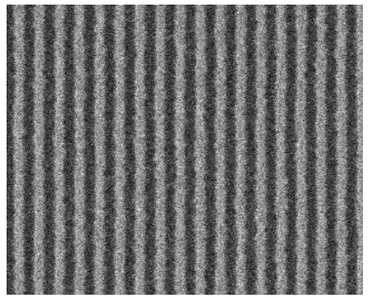
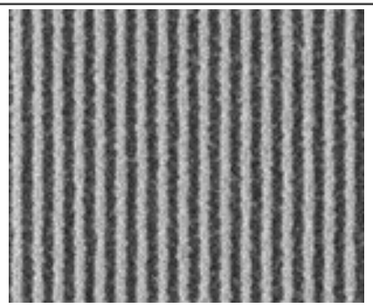
DRY RESIST EQUIPMENT AND PROCESS FLOW



With dry resist processing, holistic co-optimization can be performed at each step, both pre- and post-exposure.

EUV DRY RESIST - SUCCESSFUL IMAGING AT 26NM PITCH - Z-FACTOR <1

ASML VELDHOVEN NXE 3400, OPTIMIZED ILLUMINATION

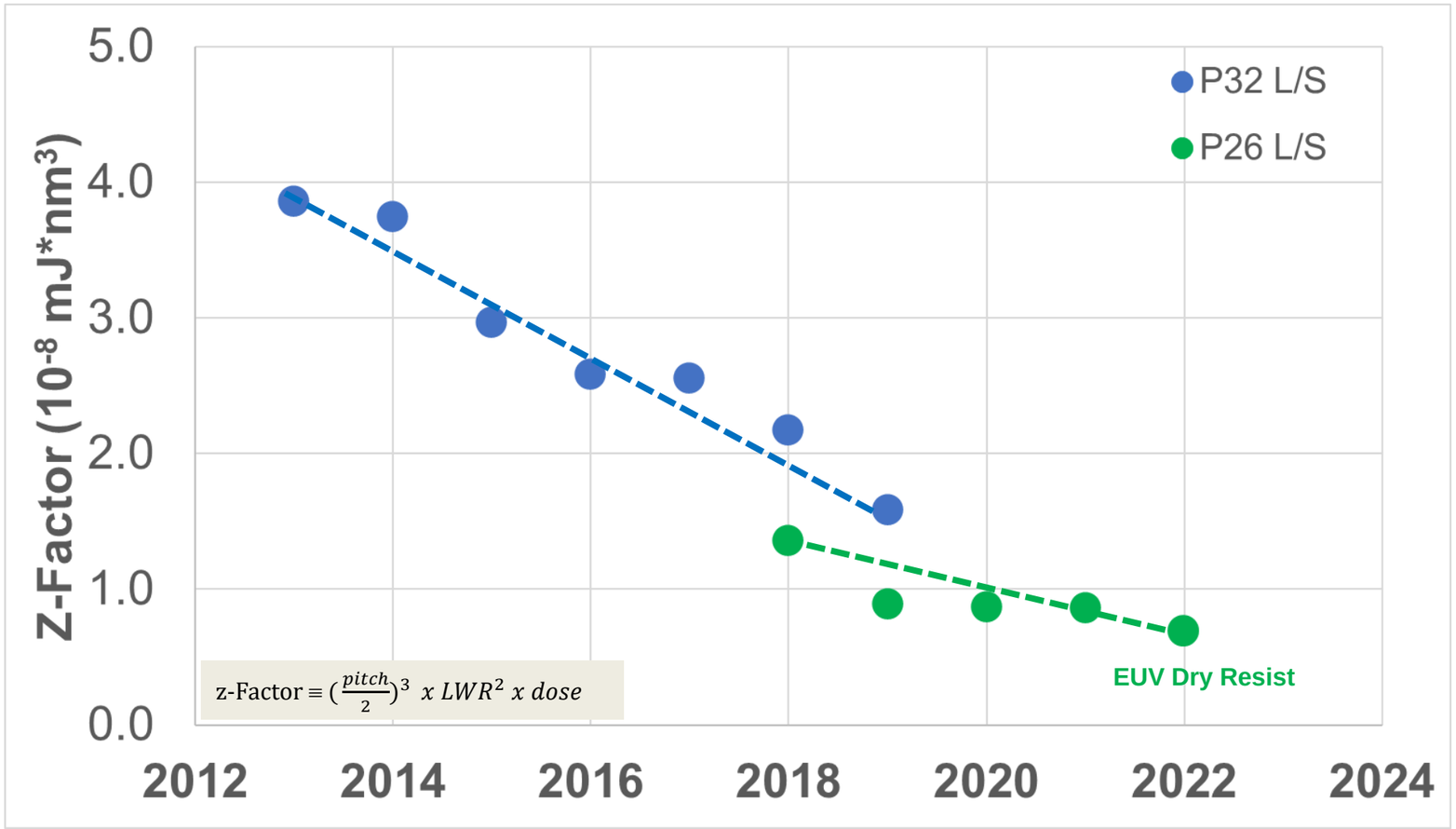
	32 nm Pitch		26 nm Pitch	
Deposition	Dry	Dry	Dry	Dry
Develop	Wet	Dry	Wet	Dry
Resist Thickness	20nm	20nm	20nm	20nm
Dose (mJ/cm^2)	47	42	39	39
EL_{max} (%)	24	35	20	26
$LWR_{unbiased}$ (nm)	3.4	3.0	2.9	3.0
z-Factor (10^{-8}mJ nm^3)	2.3	1.6	0.72	0.77
$EL = \frac{\lvert E_{(CD-10\%)} - E_{(CD+10\%)} \rvert}{E_{Nom}} \text{x } 100\%$ $\text{z-Factor} \equiv (\frac{pitch}{2})^3 \; x \; LWR^2 \; x \; dose$	 CD 16.3	 CD 16.1	 CD 13.1	 CD 12.9

EL=Exposure Latitude, LWR=Linewidth Roughness

Exposure: ASML NXE3400
Underlayer: Spin on carbon

EUV DRY RESIST FOR THE 'STOCHASTICS ERA' OF PATTERNING

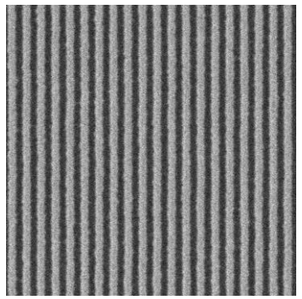
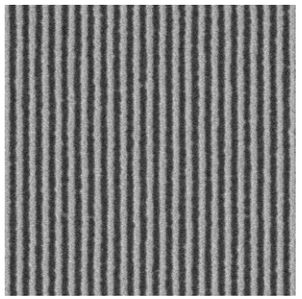
BEST IN CLASS Z-FACTOR PERFORMANCE RESULTS



Reference: Jara Santaclara, et al, 2022 SPIE Paper # 12051-7

EUV DRY RESIST - SUPERIOR IMAGE QUALITY

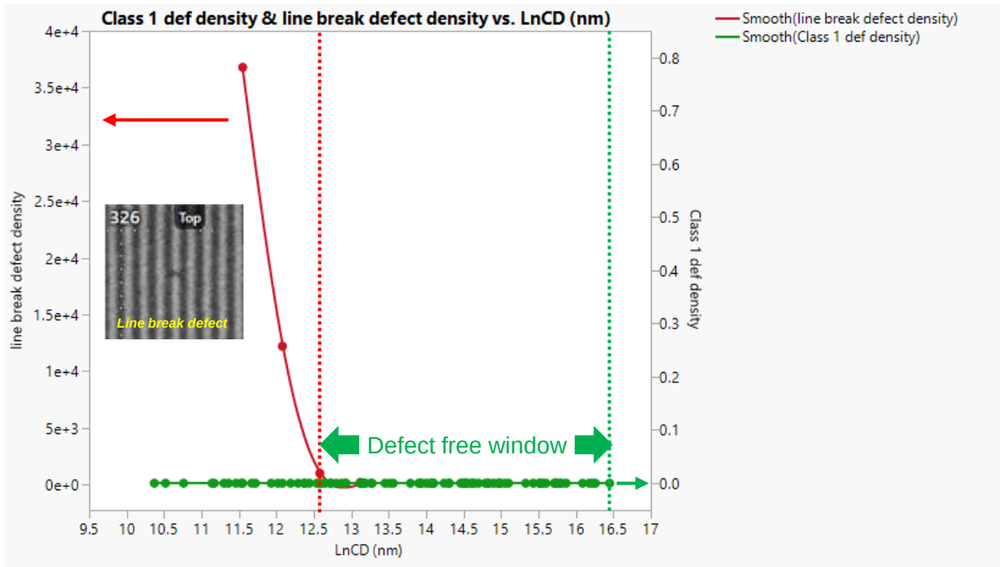
24NM PITCH 0.33NA SINGLE EXPOSURE - Z-FACTOR<0.5

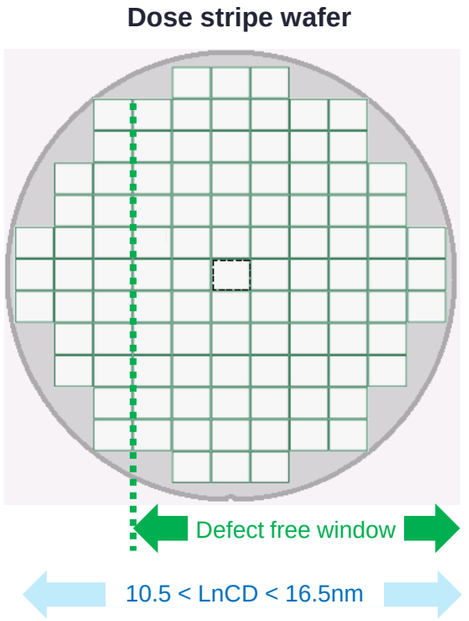
EUV Dry Resist	26nm Pitch	24nm Pitch
Resist Thickness (nm)	25	25
Underlayer	Amorphous Carbon	Amorphous Carbon
EUV Exposure	0.33NA SE	0.33NA SE
Dose (mJ/cm^2)	41.3	54.2
Development	Dry Development	Dry Development
CDSEM		
Line CD (nm)	13.6	12.0
$LWR_{unbiased}$ (nm)	2.4	2.7
z-Factor (E^{-08} mJ/nm^3)	0.3	0.4

EUV DRY RESIST – LARGE DEFECT FREE WINDOW

28NM PITCH LINE/SPACE PATTERN WAFER DEFECTIVITY AFTER PATTERN TRANSFER ETCH

ZERO BRIDGE DEFECTS DETECTED OVER THE ENTIRE WAFER (LNCD 10.5 – 16.5NM)
LINE BREAK ONLY DETECTED AT <12.5NM LNCD

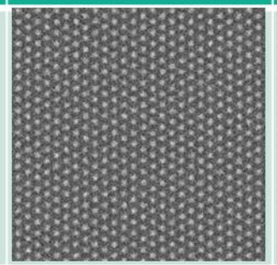
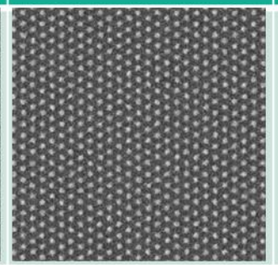
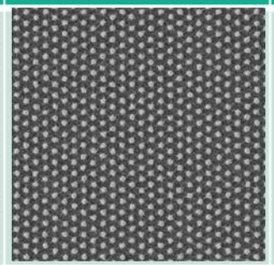
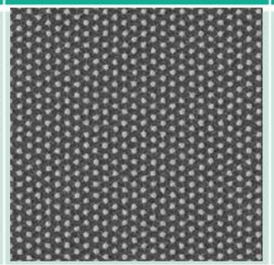
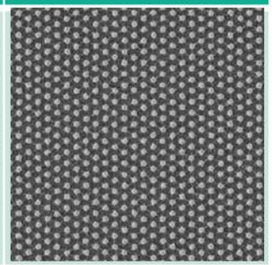


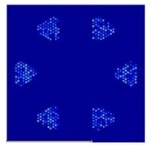


EUV Dry Resist: Dry deposition and development optimization demonstrates a defect free window >4nm

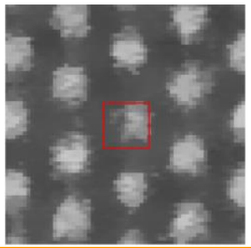
EUV DRY RESIST - ENABLES <P40NM PILLAR PATTERNING WITH 0.33NA SE

36NM PITCH PILLAR PATTERNING WITH DARK-FIELD MASK & DRY DEVELOPMENT

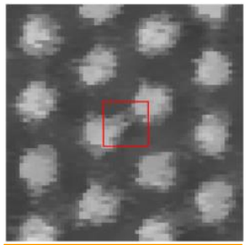
Dose	60 mJ/cm^2	72 mJ/cm^2	84 mJ/cm^2	96 mJ/cm^2	108 mJ/cm^2
P36X62nm Pillar Dark field					
CD (nm)	16.5	17.3	17.4	18.0	19.2
LCDU (nm)	4.8	3.3	2.2	2.1	2.0



2 defects in ~1 billion pillars



Partial missing pillar



Bridging pillar

eP5 mass metrology tool used

- 1.5mm^2 inspected on BDBF → ~1B pillars
- 2nm pixel size scan
- Threshold for missing pillar: 130nm
- Threshold for bridging pillar: 5nm
- Scan time: 6hr

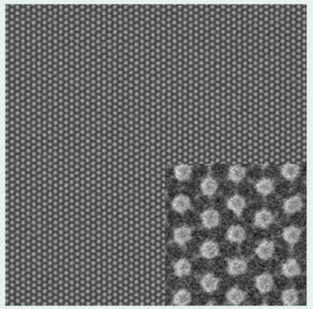
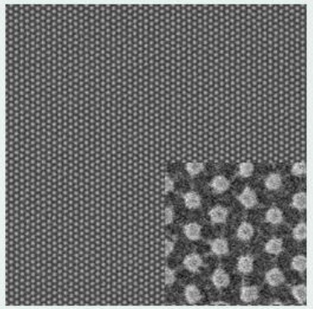
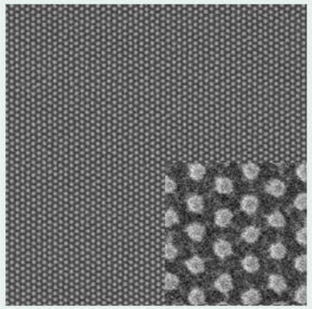
Only 2 defects reported at ADI:

- Dose: 96 mJ/cm^2
- CDSEM CD with imec BKM settings: 20.9nm

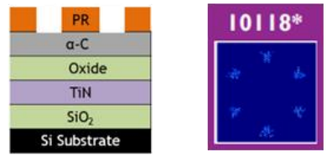
Scum-free, high-fidelity imaging over a wide CD window
Large dose window (>40mJ/cm^2) with no pattern collapse

EUV DRY RESIST - ENABLES SUCCESSFUL PITCH-32NM PILLAR PATTERNING

32NM PITCH PILLAR PATTERING WITH 0.33NA SINGLE EXPOSURE & DRY DEVELOPMENT

P32nm Pillars	P32 Bias 18/19	P32 Bias 19/20	P32 Bias 20/21
Dry Resist (nm)	25	25	25
Underlayer	Amorphous carbon	Amorphous carbon	Amorphous carbon
Dose (mJ/cm^2)	95	75	65
CD-SEM (inset is zoomed-in version for clarity)			
CD (nm)	18.2	18.4	19.2
LCDU (3σ) (nm)	1.8	2.0	2.2
X-CD/Y-CD	0.97	0.96	0.95
Metrology	MetroLER analysis of 20 images FOV of 1.638 µm x 1.638 µm		

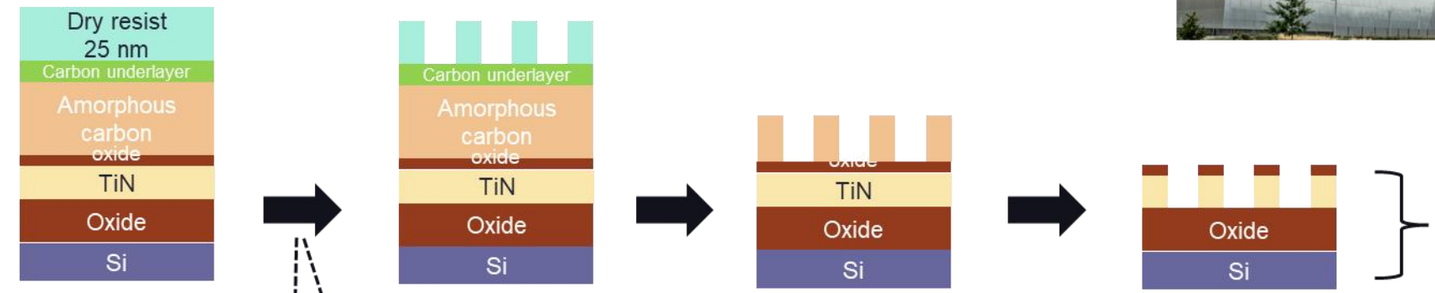
Illumination

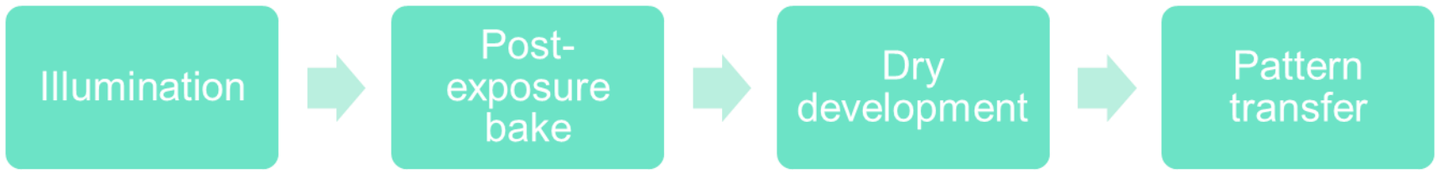


No pillar pattern collapse observed within 30mJ/cm^2 dose range
LCDU ~ 2.0 nm for P32 at 18.5nm mean CD

IMEC COLLABORATION: P24 DRY RESIST PATTERNING DEVELOPMENT FOR HIGH-NA

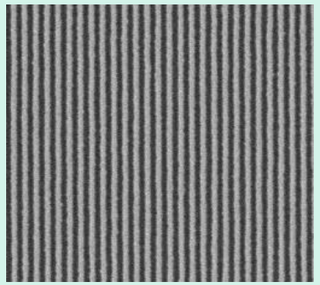
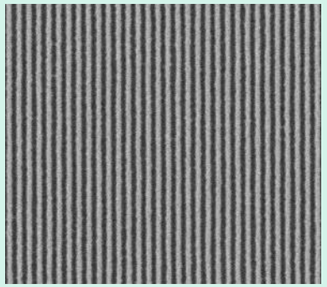
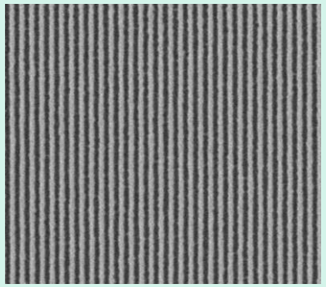
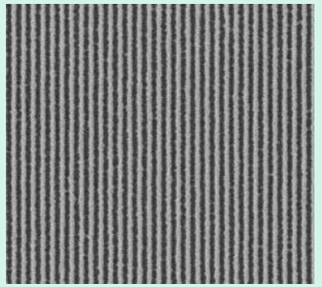
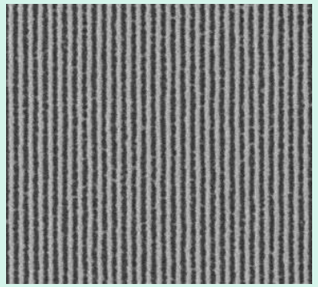
HOLISTIC APPROACH TO ACHIEVING INDUSTRY LEADING 24NM PITCH RESULTS THROUGH DRY RESIST PROCESSING





Ref. 2023 SPIE Advanced Lithography + Patterning (Paper #: 12498-1)

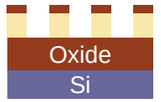
PEB OPTIMIZATION IS A KEY FACTOR IN REDUCING DOSE TO SIZE (DTS)

PEB condition	PEB 1	PEB 2	PEB 3	PEB 4	PEB 5
CD-SEM image					
Mean CD (nm)	12.12 nm	12.24 nm	12.53 nm	11.92 nm	12.01 nm
DtS (mJ/cm2)	71.02	54.55	45.58	36.23	29.97
uLWR/uLER(nm)	2.11 / 1.81	2.36 / 1.87	2.62 / 2.02	3.26 / 2.52	4.02 / 3.17
Z-factor	0.40 (E-8)	0.33 (E-8)	0.32 (E-8)	0.40 (E-8)	0.52 (E-8)
FFL (nm)	1.67	1.61	0	0	0

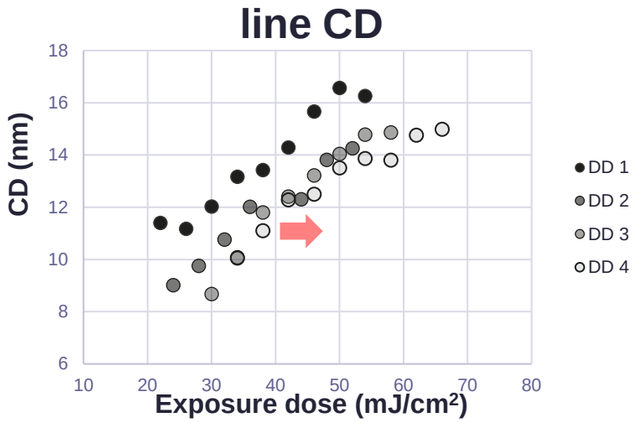
Ref. 2023 SPIE Advanced Lithography + Patterning (Paper #: 12498-1)

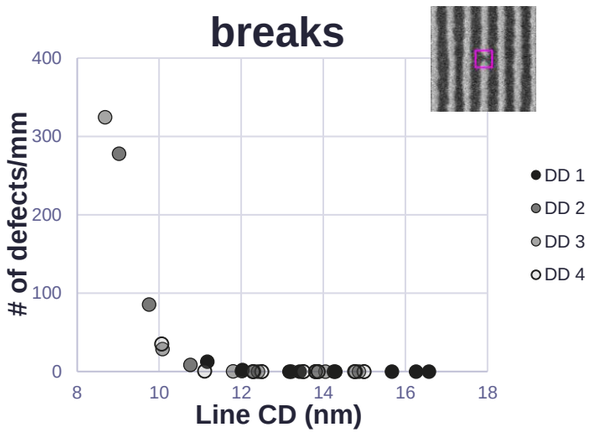
Need to address the degradation in roughness and defectivity

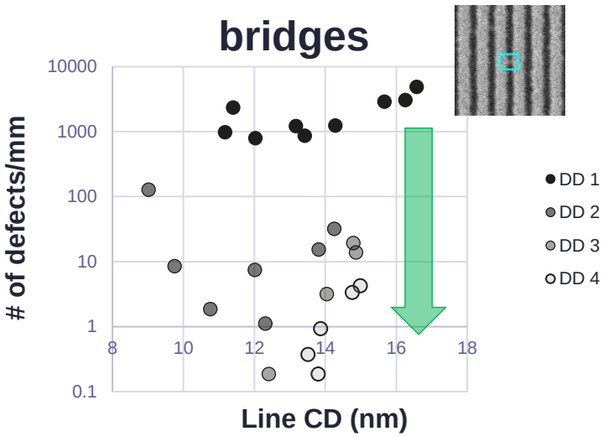
IMPACT OF DRY DEVELOPMENT OPTIMIZATION



Post etch (AEI) measure

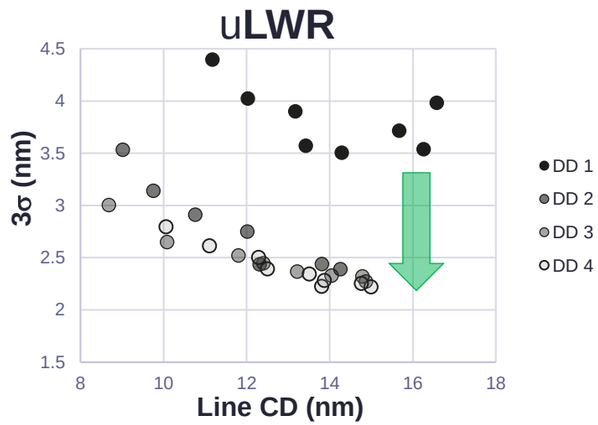


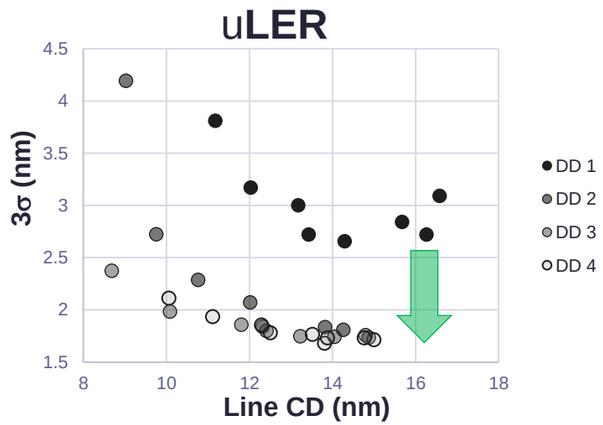




Significant return (mitigation of bridge defect, roughness) on the investment (dose)

Negligible impact on breaks

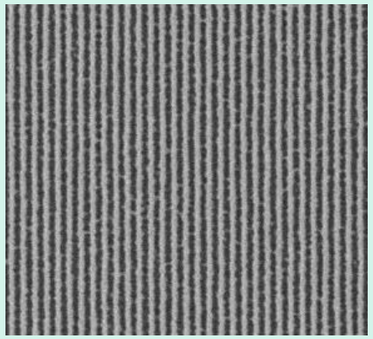
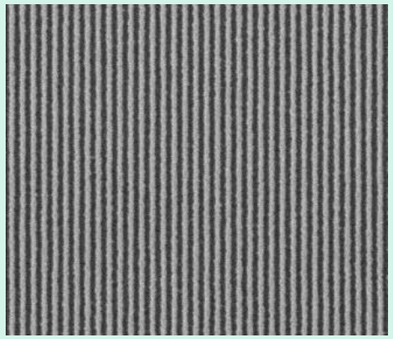
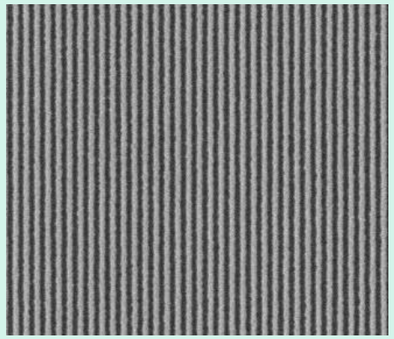
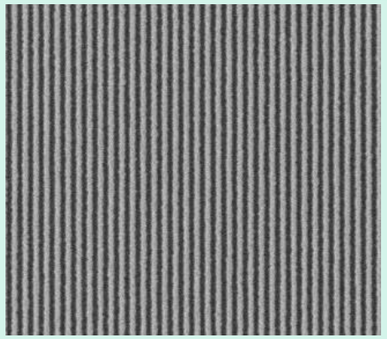




Ref. 2023 SPIE Advanced Lithography + Patterning (Paper #: 12498-1)

DRY DEVELOPMENT ROUGHNESS AND DEFECTIVITY MITIGATION RESULTS

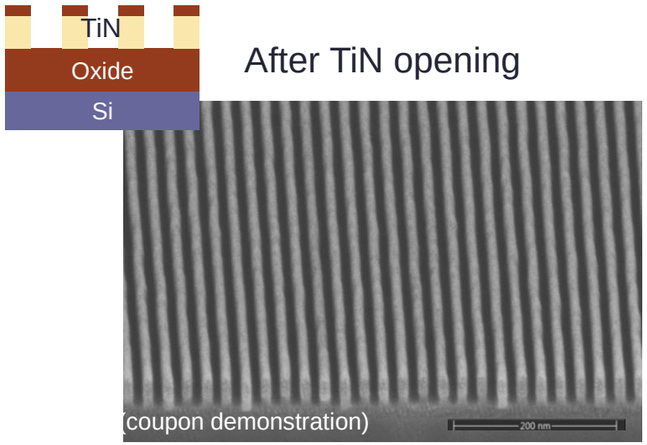
IMPROVED ROUGHNESS AND DEFECTIVITY AT LOWER DOSE

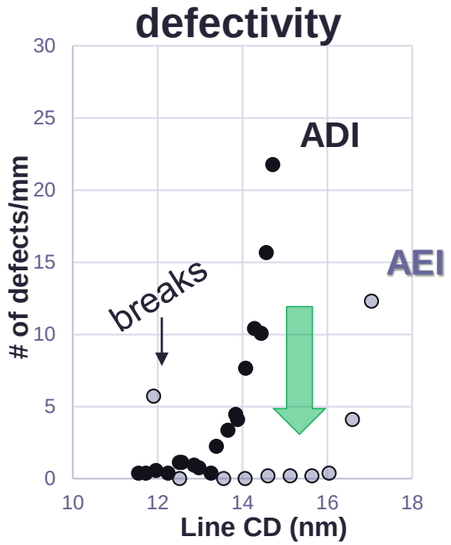
Dry development	DD 1	DD 2	DD 3	DD 4
CD-SEM image				
Mean CD (nm)	12.01	12.01	12.40	12.50
PEB				
DtS (mJ/cm2)	**29.97**	**39.32**	**40.65**	**42.81**
unbiased LWR/LER (nm)	4.02/3.17	2.75/2.07	2.44/1.79	2.39/1.78
Z-factor	0.52 (E-8)	0.29 (E-8)	0.23 (E-8)	0.23 (E-8)
FFL (nm)	0	0.014	2.24	3.88

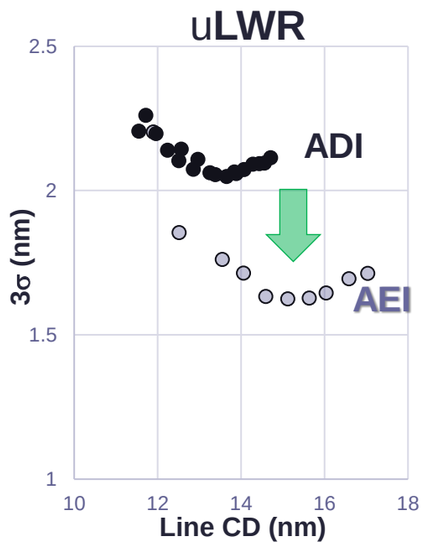
Was 54.55

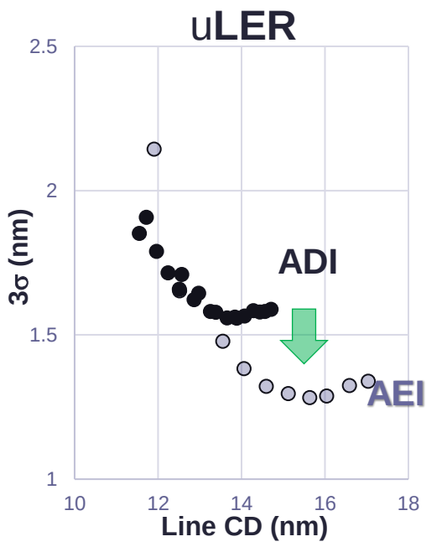
Ref. 2023 SPIE Advanced Lithography + Patterning (Paper #: 12498-1)

DRY ETCH: ADDITIONAL KNOB TO FURTHER REDUCE DEFECTIVITY AND ROUGHNESS









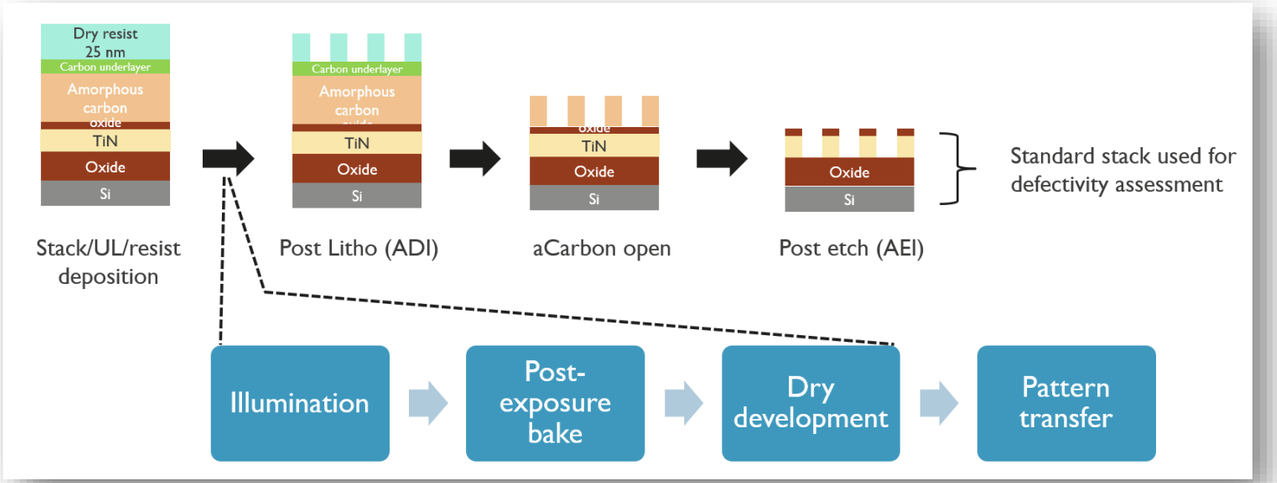
PEB condition 6 / Dry development condition 1

- Large reduction in bridge defects
- Post pattern transfer roughness improvement
- FFL increased from 2.34 nm to 4.07 nm
- Line breaks started to increase at CD < 12 nm
- AEI process window improved over ADI process window

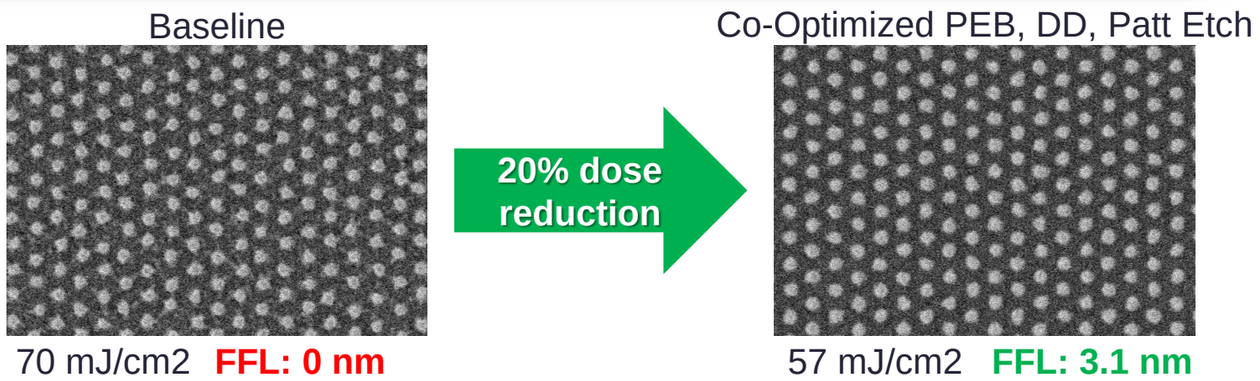
ADI: after development inspection
AEI: after etch inspection

Ref. 2023 SPIE Advanced Lithography + Patterning (Paper #: 12498-1)

HOLISTIC APPROACH: DOSE-TO-DEFECTIVITY CONTROL ENABLEMENT



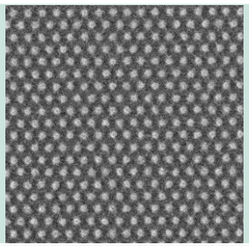
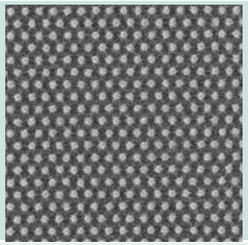
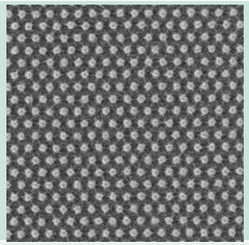
Example:
Hexagonal pillars
center-to-center 32 nm

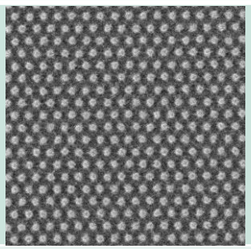
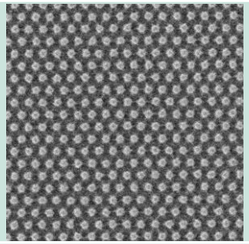
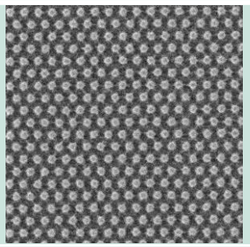


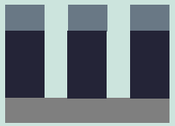
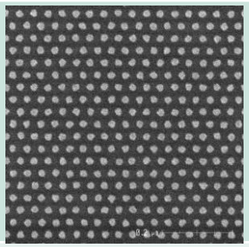
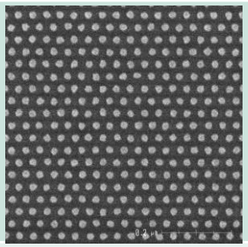
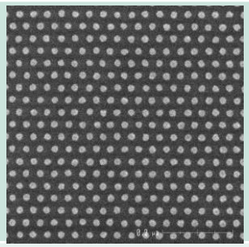
Ref. 2023 SPIE Advanced Lithography + Patterning (Paper #: 12498-1)

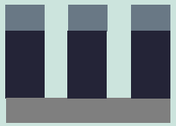
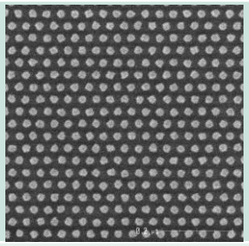
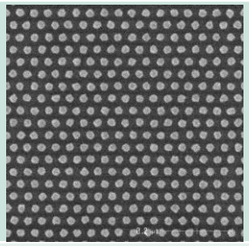
EUV DRY RESIST - LCDU IMPROVES POST ETCH AT LOWER DOSES

PILLAR INTEGRITY MAINTAINED OVER ENTIRE DOSE RANGE AS VERIFIED BY CDSEM INSPECTION

Dose	57 mJ/cm²	65 mJ/cm²	73 mJ/cm²
ADI **P36X62nm** Mask Bias 23 nm			
CD (nm)	19.4	20.1	21.5
LCDU (nm)	3.7	2.7	2.1

Dose	57 mJ/cm²	65 mJ/cm²	73 mJ/cm²
ADI **P36X62nm** Mask Bias 24.5 nm			
CD (nm)	20.6	22.2	23.2
LCDU (nm)	2.7	2.1	1.8

AEI P36nm	Etch-1	Etch-2	Etch-3
Pattern transfer 			
CD (nm)	18.7	18.7	18.0
LCDU (nm)	1.8	2.0	2.3

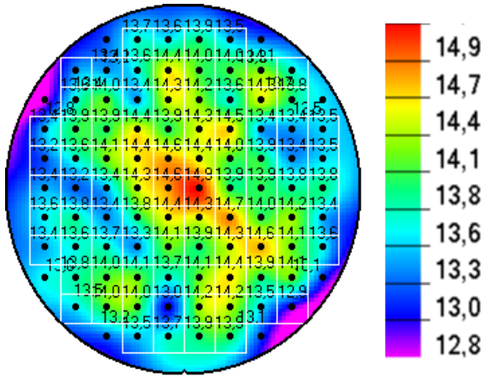
AEI P36nm	Etch-1	Etch-2	Etch-3
Pattern transfer 			
CD (nm)	21.2	21.6	20.7
LCDU (nm)	2.1	1.8	1.9

Pillar defects were also ‘healed’ after etch with no observed scumming

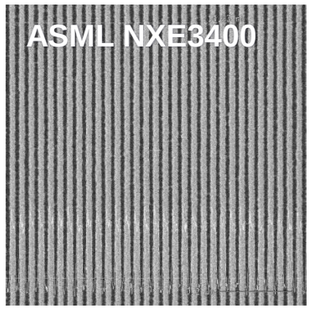
EUV DRY RESIST – HIGH ELECTRICAL YIELD AND HOT SPOT FIDELITY AT P26

LITHO-TO-ETCH CD BIAS ~0.1NM, AEI WCDU ~0.8NM

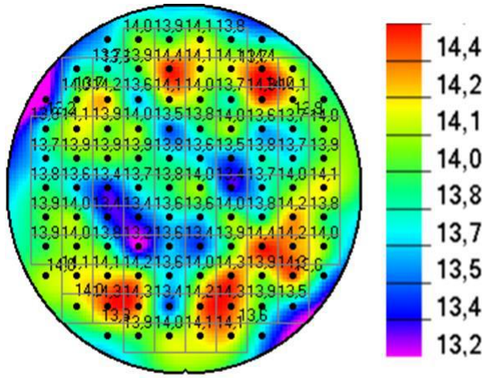
Post develop



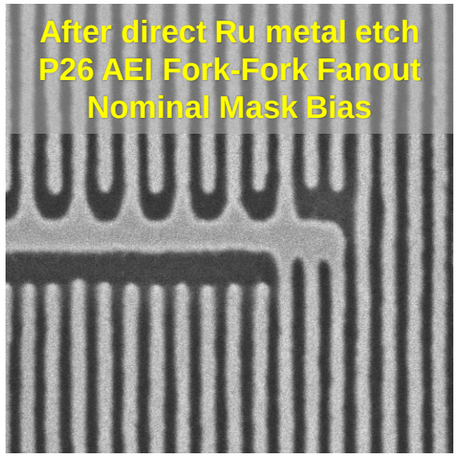
Mean : 13,8 nm
3-sigma: 1,3 nm (9,3 %)
Range : 2,2 nm (15,8 %)
LWR_{biased}: 2.8 nm
LER_{biased}: 2.0 nm

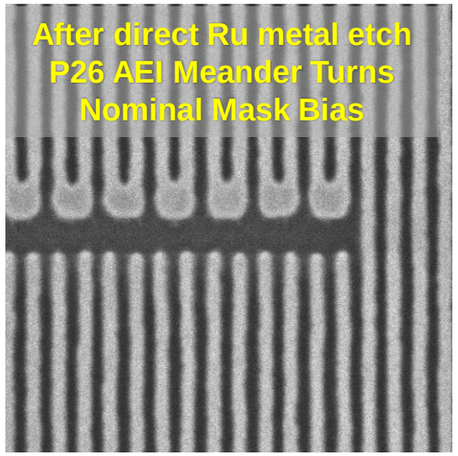


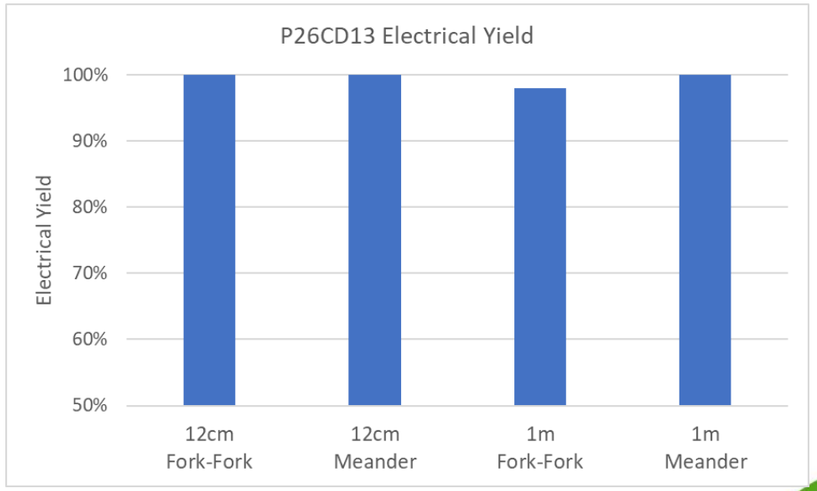
Post metal etch



Mean : 13,9 nm
3-sigma: 0,8 nm (5,9 %)
Range : 1,2 nm (8,4 %)
LWR_{biased}: 2.3 nm
LER_{biased}: 1.8 nm

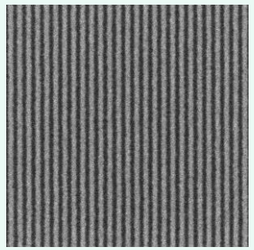
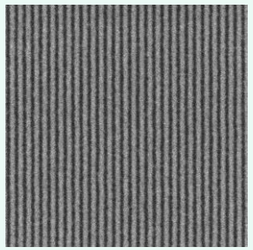
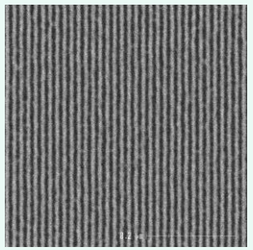


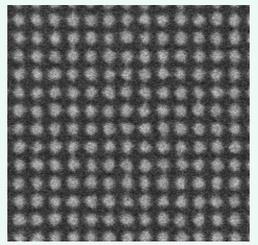
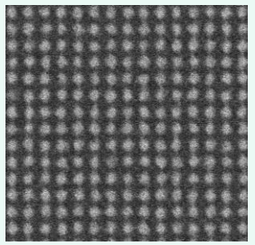




EUV DRY RESIST - READINESS FOR HIGH-NA PATTERNING

EXTENDABLE TO SUB 20NM PITCH L/S & 24NM PITCH PILLARS; Z-FACTOR ~ 0.2 X 10^{-8} MJNM^3*

Line/Space	20nm Pitch	18nm Pitch	16nm Pitch
Dry Resist (nm)	15	15	15
Underlayer	Amorphous carbon	Amorphous carbon	Amorphous carbon
Dose (mJ/cm^2)	60	60	60
CD-SEM			
Line CD (nm)	10	9	8
LWR_{unbias} (nm)	2.1	2.1	2.6
z-Factor (10^{-8} $mJ*nm^3$)	0.26	0.19	0.21

Pillar	24nm Pitch	22nm Pitch
Dry Resist (nm)	25	25
Underlayer	Amorphous carbon	Amorphous carbon
Dose (mJ/cm^2)	50	54
CD-SEM		
Line CD (nm)	14.9	13.0
LCDU (nm)	2.1	2.3
Aspect Ratio	~1.5:1	~1.5:1

Excellent MET5 resolution at the 0.5NA LBNL beamline
Demonstrated capability for 16nm pitch line/space and 22nm pitch orthogonal pillars

SUMMARY

+EUV dry resist, coupled with ASML's EUV scanners and Lam's holistic patterning solutions, will extend the patterning roadmap (Moore's Law) for 10 years and beyond.

+EUV dry resist offers a high-resolution, high-fidelity, defectivity-free, and greener solution for ≤32nm pitch L/S, and ≤40nm pitch pillar and contact hole EUV patterning in the fab.

+EUV dry resist technology has been validated by superior dose-to-defectivity for <32nm pitch L/S, well suited for logic applications.

+EUV dry resist technology offers ultra-low capillary force during processing, making it ideally suited for pillar and high aspect ratio patterning.

+EUV dry resist is uniquely suited for future HiNA EUV patterning thanks to robust resist thickness scaling maintaining high etch selectivity and high contrast.

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BUILDING A PATH FORWARD

THANK YOU

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