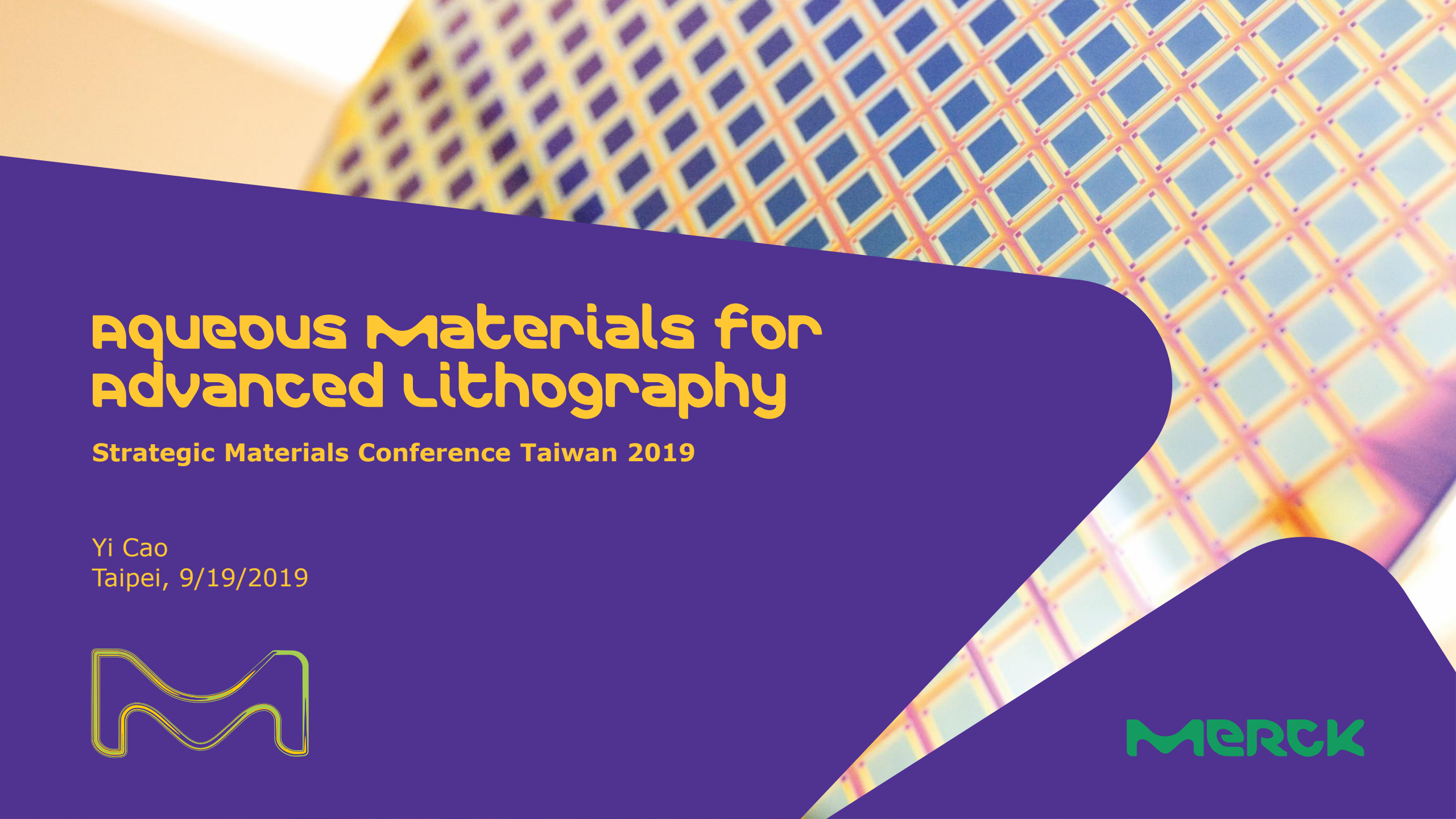


Aqueous Materials for Advanced Lithography

Strategic Materials Conference Taiwan 2019

Yi Cao
Taipei, 9/19/2019

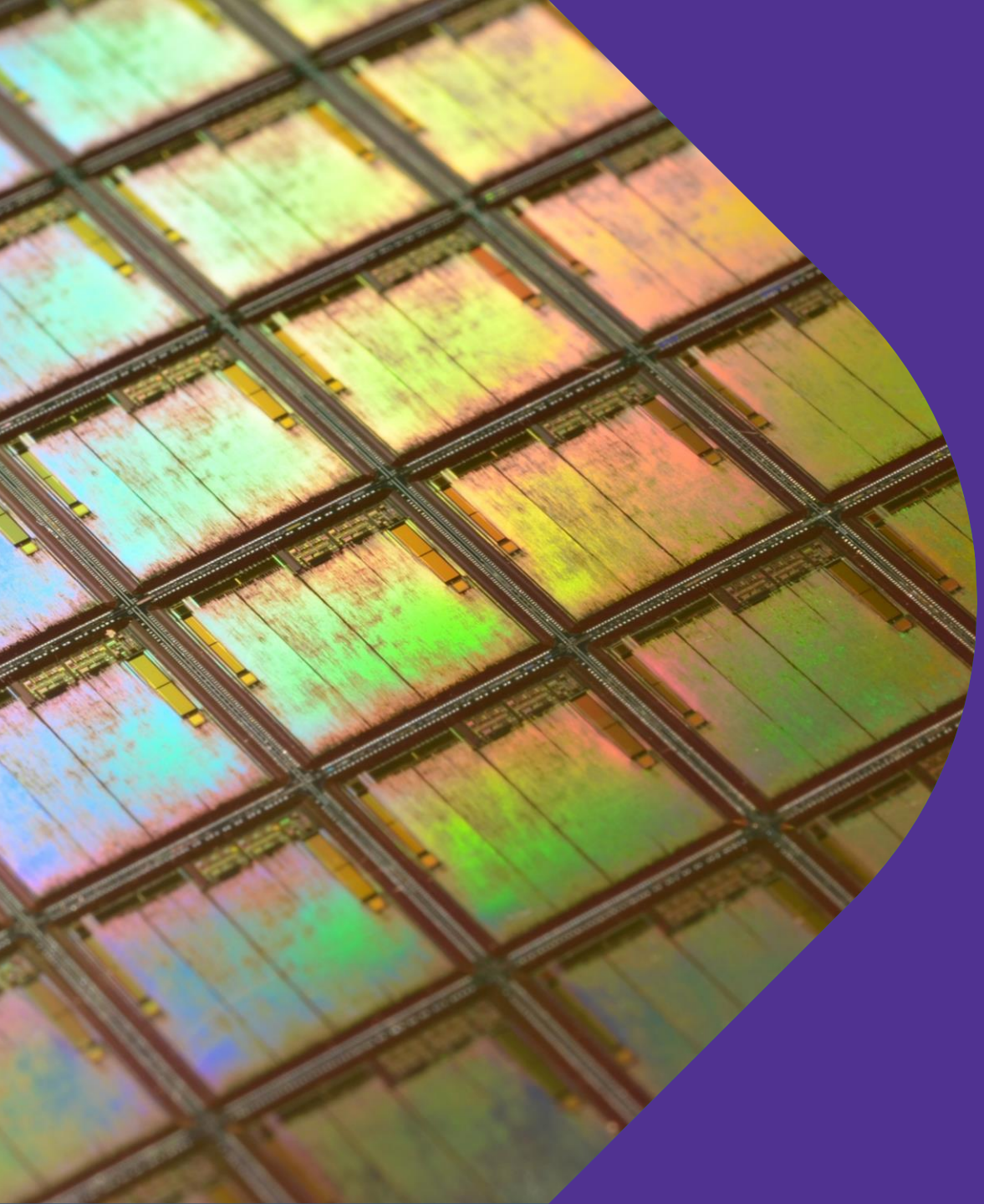
Agenda

01 Overview and product roadmap

02 Rinse materials

03 Chemical shrink materials

04 Summary



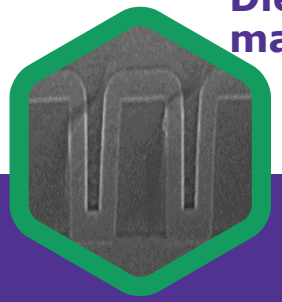
01 overview and product roadmap

MERCK

Merck Performance Materials – Semiconductor Solutions
Our solutions enable electronic industry

Patterning materials

Dielectric materials



Deposition materials

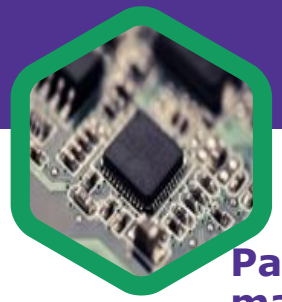
we enable

- smaller structures to continue Moore's law
- higher memory capacity, faster processing speed and less power consumption
- improved yields and lower processing costs

Process materials

CMP materials

Packaging materials



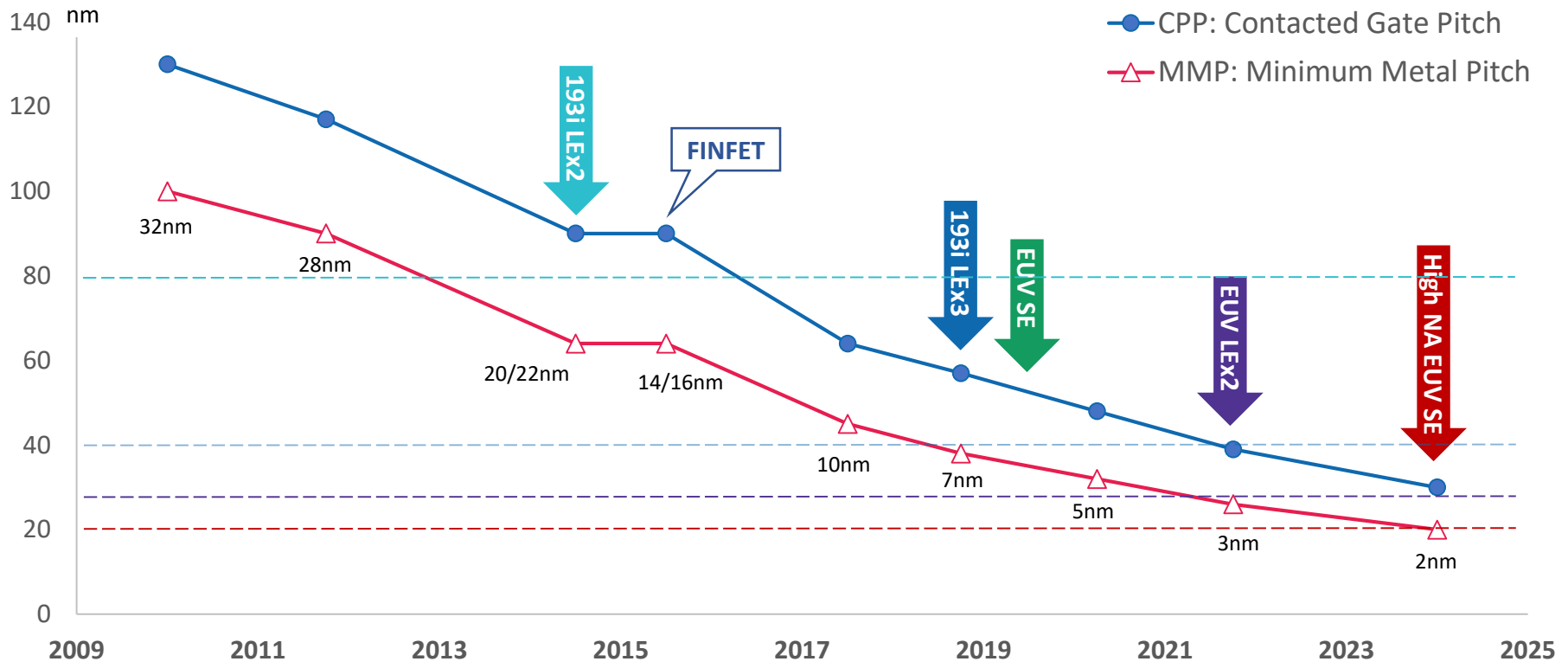
Mobile Devices

Servers for Big Data

Wearables and other IoT devices

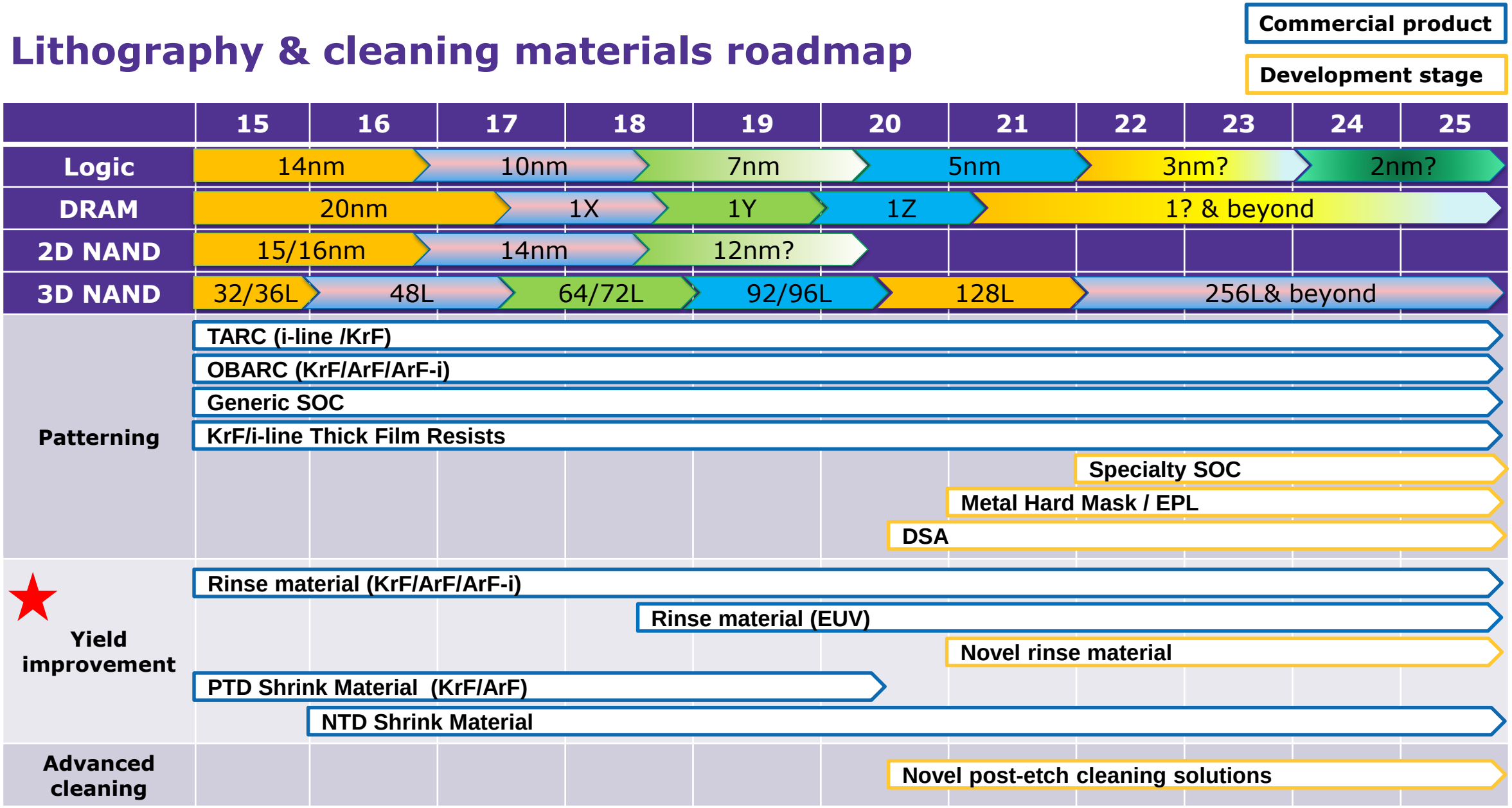
Further expanded portfolio with the on-going Versum acquisition

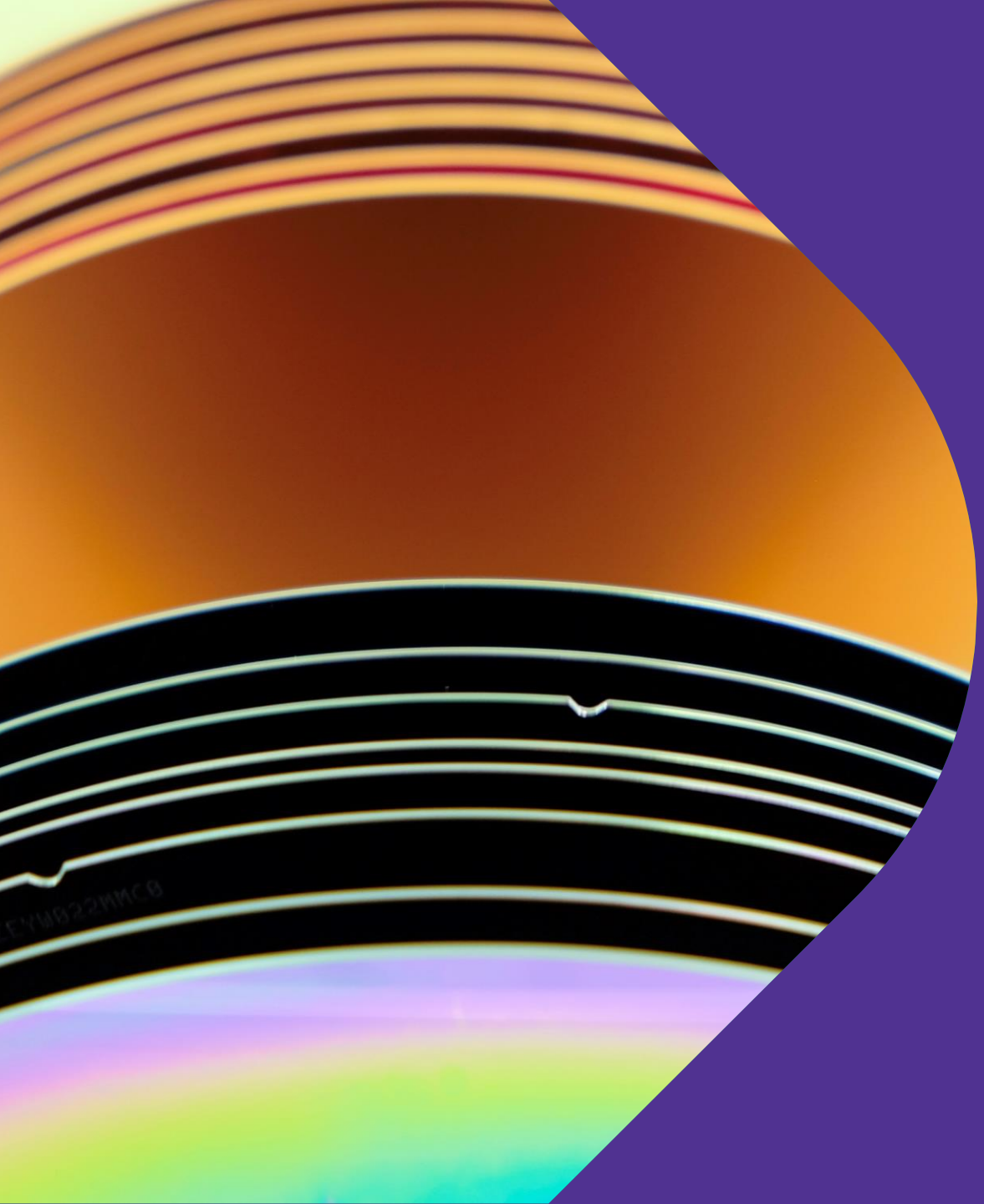
Lithography roadmap



- ✓ EUV process makes economic sense when replacing 3 masks.
- ✓ Double SAQP for pillar patterning may render EUV process of cost advantages.

Lithography & cleaning materials roadmap



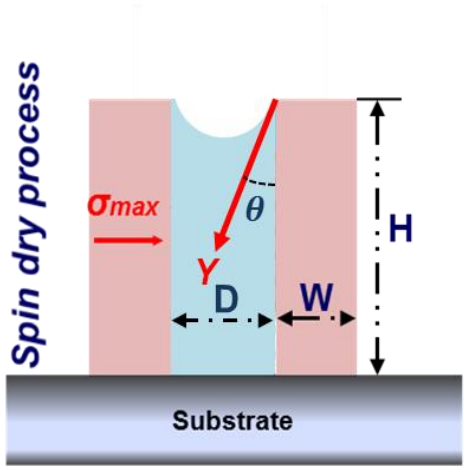


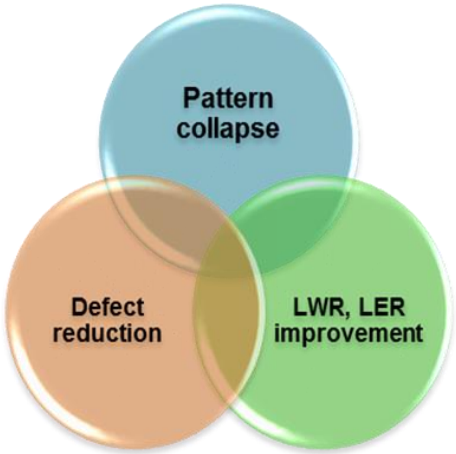
02 Rinse Materials

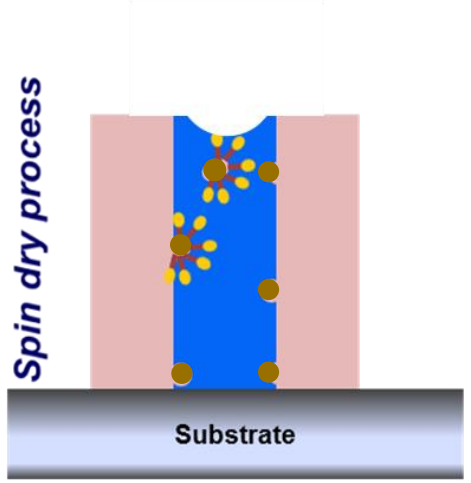
Rinse materials
Concept

Pattern collapse:
- Capillary effect (rinse surface tension)
- Resist deformation (Young's modulus)

Defect reduction & LWR, LER improvement:
- Resist & DIW affinity part of FIRM chemical
- Clean resist scum & leveling pattern surface



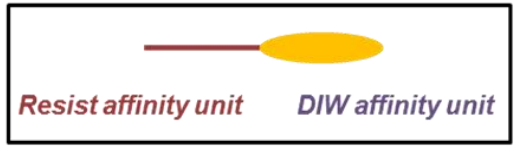




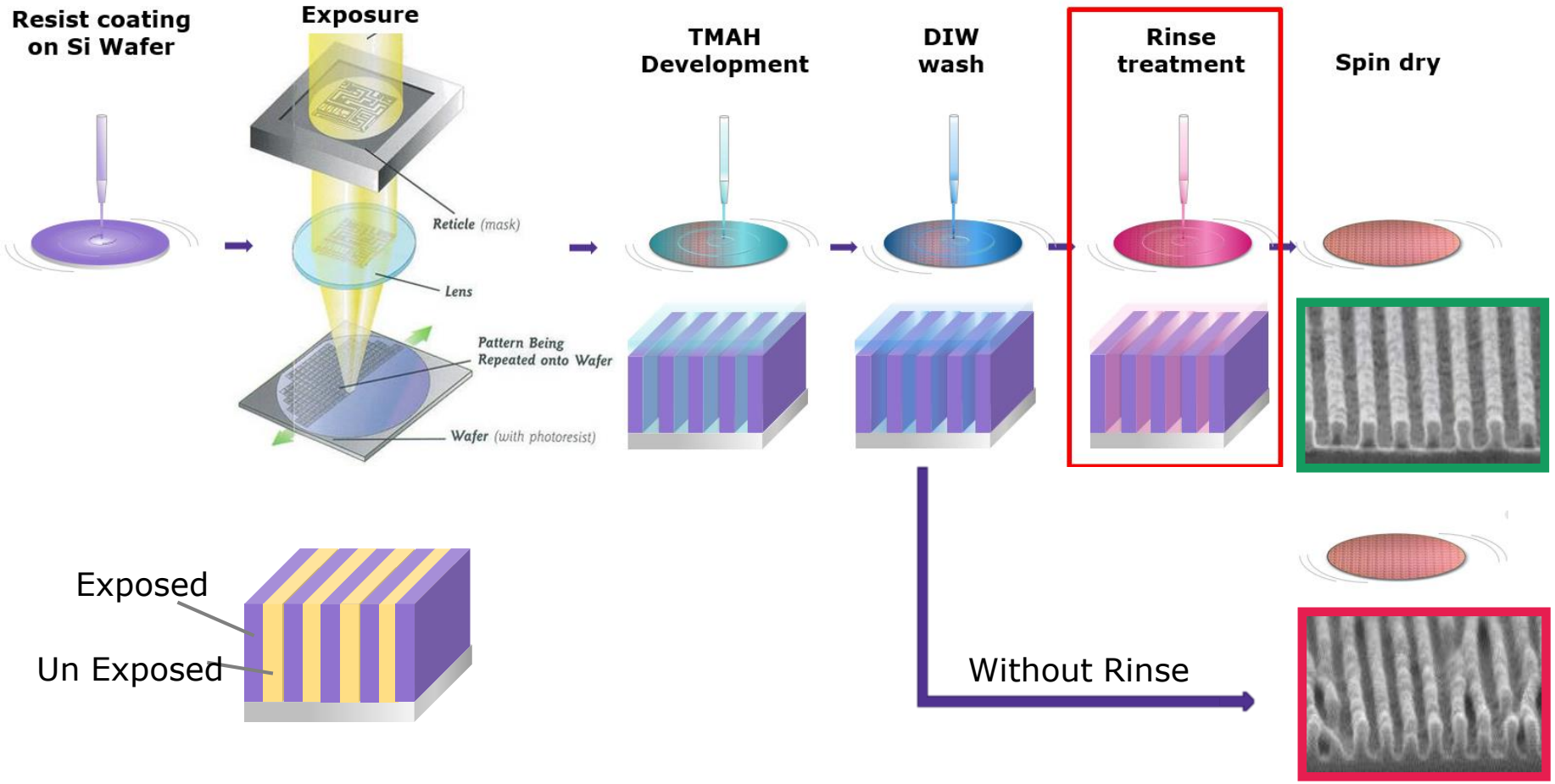
$$\sigma_{max} = 6\gamma A^2 \bullet \cos\theta / D$$

σ : Stress to resist
γ : Surface tension of rinse
A : Aspect ratio = H/W
Θ : Contact angle
D : Space width

FIRM chemistry

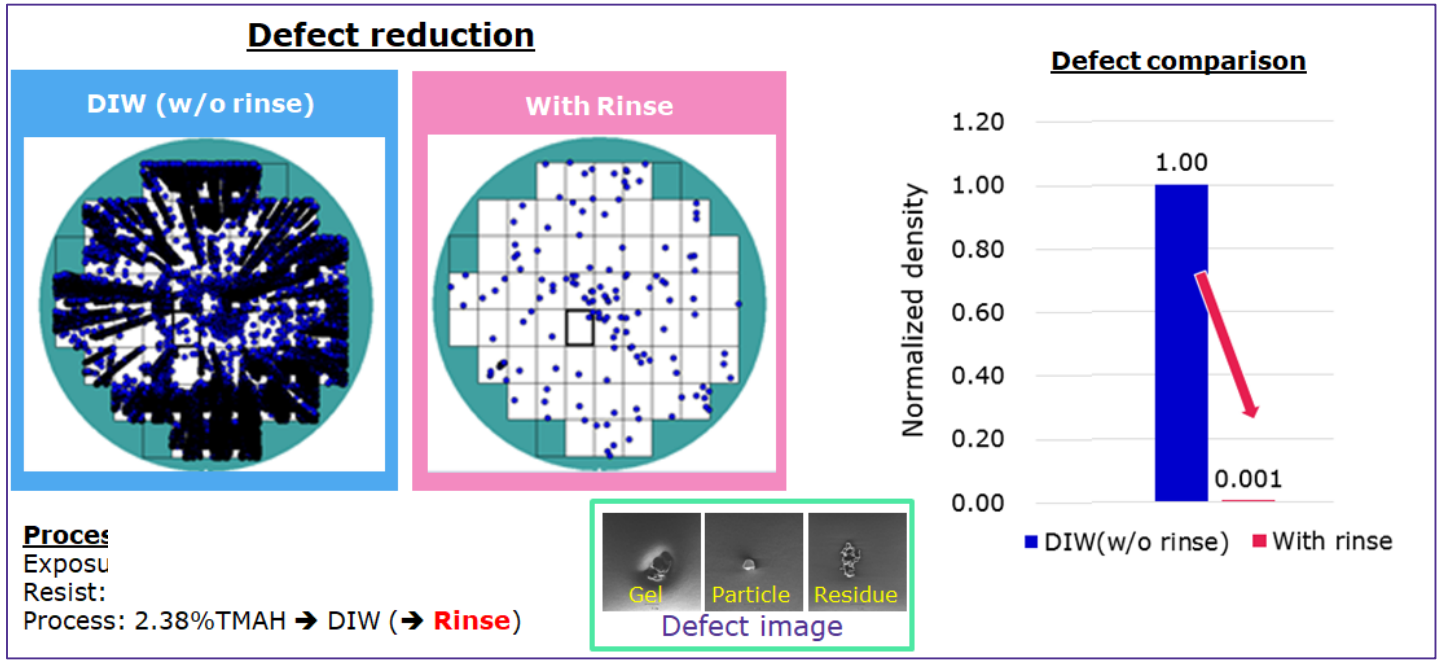


Rinse materials
The process and benefits



Fully integrated in resist development

Rinse materials
The process and benefits

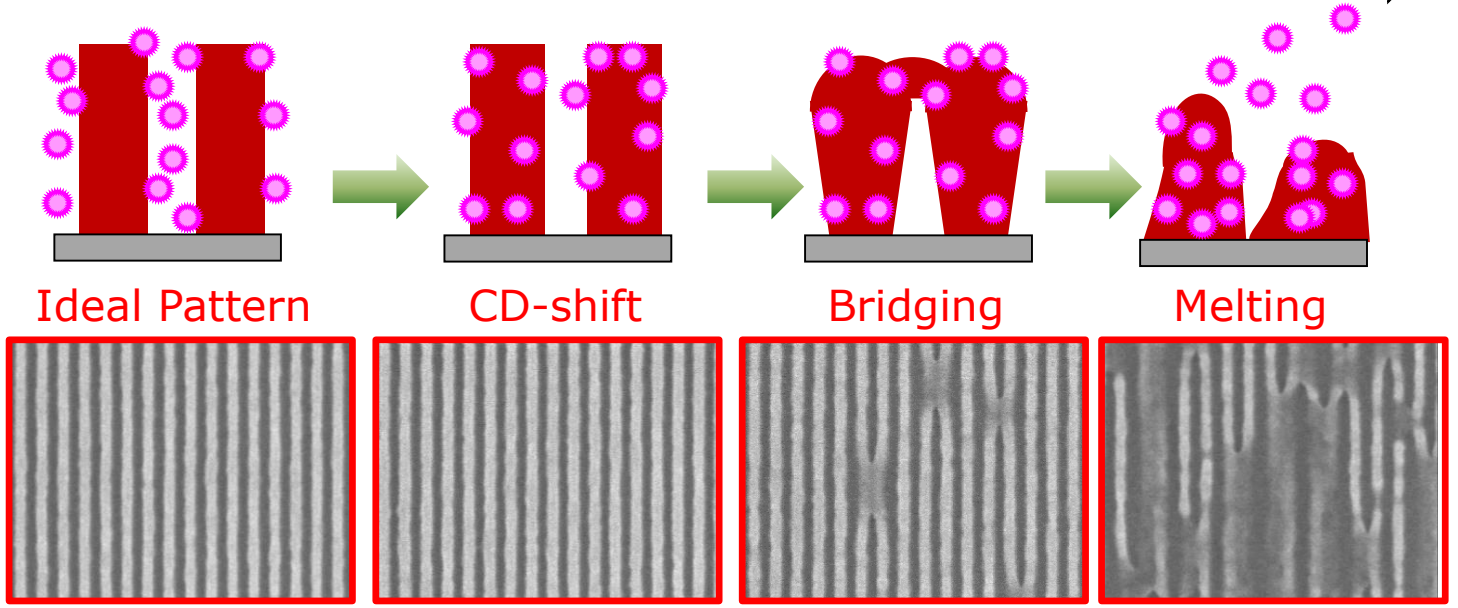


Key Benefits

- ✓ Straightforward process
- ✓ Pattern collapse mitigation
- ✓ Defect reduction

Rinse materials
Material design

Low → ***Affinity between resist and surfactant** (Penetration of surfactant into resist pattern) → **High**



*The affinity is defined by solubility parameter.

Considerations

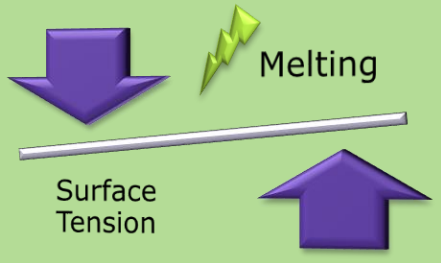
- Resist chemistry
- Loading of surfactants
- Bulkiness of surfactants
- Melting control
- Functionality

Surfactant penetration is one of the key factors for resist compatibility

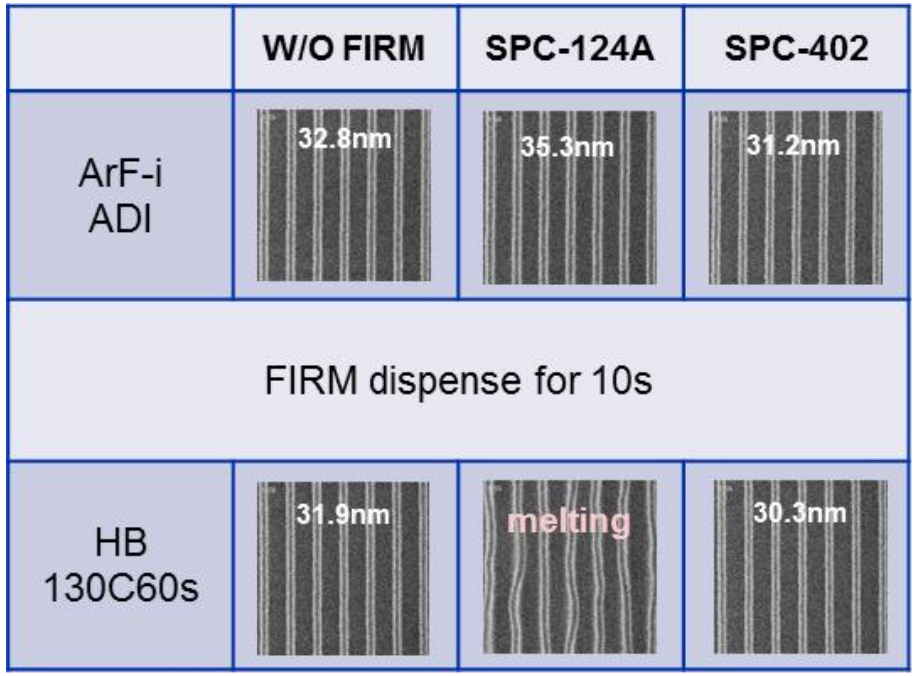
Rinse materials – ArF
Commercial products

Product Name	SPC-116A	SPC-124A	SPC-402
*Surface tension (mN/m)	33.3	37.5	33.4
Chemical	Nonionic	Nonionic	Nonionic + Additive
Application	ArF-d	KrF & ArF-d (ArF-i)	ArF-i

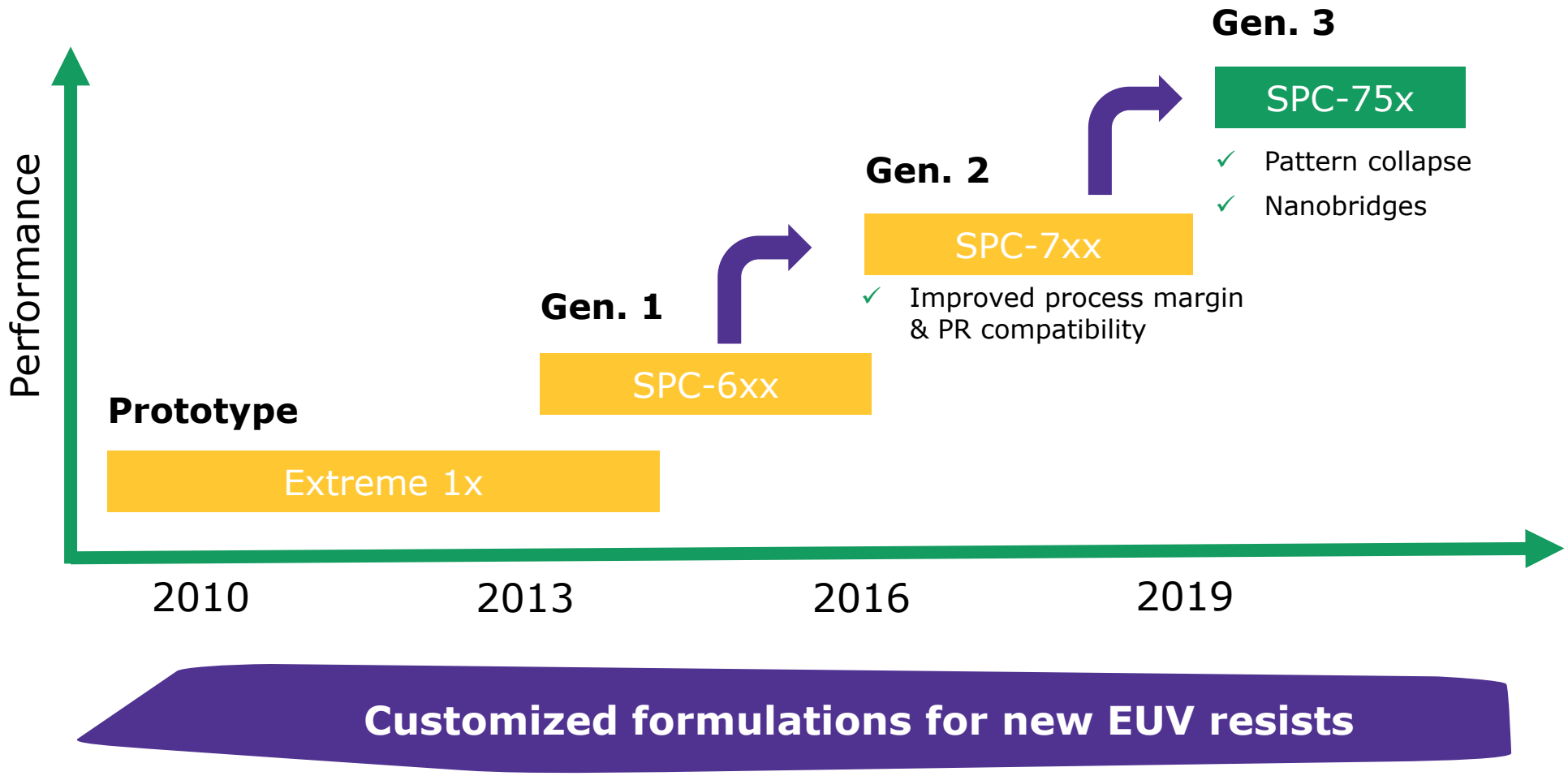
Introduction of melting inhibitor



- Broadly adopted in the industry.
- Proven resist compatibility.



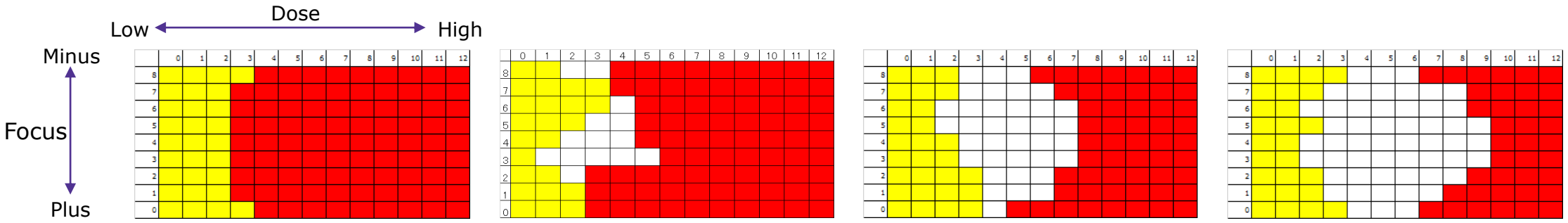
Rinse materials
EUV Rinse – development roadmap



Rinse materials
Lithographic performance on EUV Resist B

Process conditions
Exposure tool: NXE3300 (0.33NA, Dipole)
EUV Resist B/ 45nm thick (**16nm L/S**)
Dose: 41 mJ/cm^2 center / 1.5mJ/cm^2 step
Focus: 0.02um center / 0.02um step

	DIW	Gen. 2	Gen. 3
Minimum CD (nm) (Pattern collapse margin)	N/A	15.5	14.5



Bridge
Collapse or Pinching
Pattern standing

Expanded process margin with new rinse platforms.

Rinse materials
Lithographic performance on EUV Resist C

Process conditions
Exposure tool: NXE3300 (0.33NA, Dipole)
EUV Resist C / 35nm thick (**16/nm hp**)
Dose: 53 mJ/cm^2 center / 2.0mJ/cm^2 step
Focus: 0.04um center / 0.02um step

Dose: Low ⟷ High
Focus: Minus ↕ Plus

P32V16	37	39	41	43	45	47	49	51	53	57	59	61	63	65	67	69	71
-0.04				18.87	17.89	16.87	15.86	14.97	13.84	12.73							
-0.02		21.26	19.99	18.95	18.02	17.2	16.34	15.48	14.45	13.57	13.28						
0	22.11	21.32	20.07	19.03	18.14	17.31	16.54	15.71	14.87	14.14	13.27	12.79					
0.02	22.21	21.19	20.08	19.12	18.24	17.41	16.53	15.77	14.97	14.35	13.65	12.81					
0.04	22.23	21.3	20.08	19.17	18.28	17.45	16.69	15.81	15.22	14.45	13.82	13.16	12.54				
0.06	22.23	21.19	20.08	19.03	18.31	17.44	16.7	15.94	15.22	14.73	13.89	13.16	12.65				
0.08	22.22	21.29	20.05	19.06	18.23	17.46	16.76	15.94	15.28	14.55	13.77	13.48	12.38				
0.1		21.24	20.1	19.03	18.15	17.3	16.58	15.88	15.16	14.38	13.61	12.86	12.55				
0.12				19.03	18.15	17.23	16.41	15.62	14.93	14.03	13.23	12.49					

Gen. 2

65 blocks

P32V16	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65	67	69
-0.04				19.13	18.15	17.2	16.33	15.38	14.35	12.86							
-0.02		21.55	20.29	19.33	18.32	17.5	16.69	15.87	14.83	14.1	13.15						
0	22.32	21.5	20.34	19.32	18.55	17.65	16.89	16.08	15.3	14.57	13.79	13.19					
0.02	22.34	21.43	20.35	19.44	18.54	17.81	16.94	16.15	15.43	14.7	14.06	13.32	12.53				
0.04	22.37	21.53	20.37	19.42	18.66	17.76	16.97	16.16	15.53	14.84	14.08	13.53	12.78				
0.06	22.36	21.48	20.29	19.37	18.6	17.74	17.12	16.21	15.5	15	14.2	13.47	12.76	13			
0.08	22.37	21.4	20.35	19.36	18.58	17.76	17.11	16.23	15.73	14.95	14.09	13.37	12.6	12			
0.1		21.44	20.32	19.29	18.46	17.57	16.91	16.13	15.39	14.66	13.87	13.15	12.32	12			
0.12				19.26	18.3	17.51	16.67	15.92	15.14	14.31	13.41	12.55					

Gen. 3

71 blocks

P32V16	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65	67	69
-0.04				19.43	18.52	17.54	16.7	15.68	14.74	13.64							
-0.02		21.76	20.58	19.63	18.64	17.78	16.91	16.05	15.3	14.34	13.53	12.24					
0	22.43	21.71	20.57	19.62	18.77	17.87	17.08	16.35	15.46	14.75	13.95	13.18					
0.02	22.51	21.59	20.59	19.6	18.82	18.01	17.1	16.42	15.67	14.96	14.28	13.53	12.76				
0.04	22.53	21.73	20.64	19.67	18.86	18.05	17.22	16.38	15.74	15.07	14.4	13.67	12.81	13			
0.06	22.44	21.58	20.54	19.66	18.86	18.02	17.28	16.43	15.79	15.29	14.44	13.79	13	13			
0.08	22.44	21.68	20.64	19.64	18.77	17.95	17.3	16.43	17.21	15.23	14.43	13.62	12.82	12			
0.1		21.61	20.6	19.59	18.68	17.81	17.17	16.38	15.68	14.85	14.13	13.28	12.5	12			
0.12				19.49	18.58	17.77	16.94	16.17	15.42	14.65	13.72	12.75	12.21				

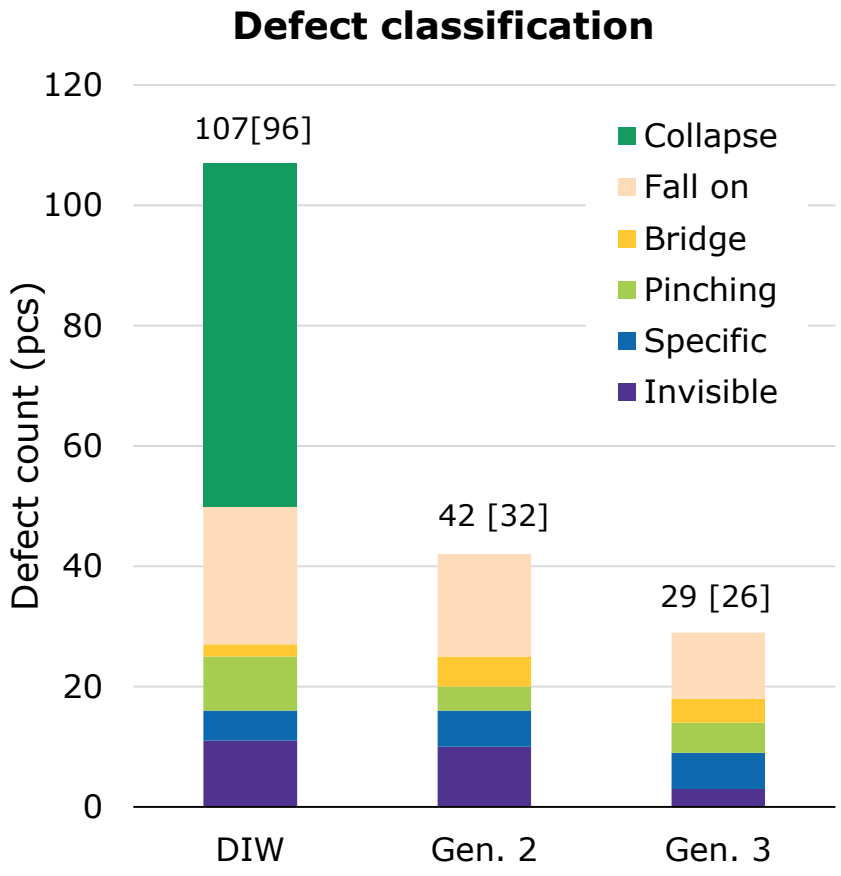
Gen. 3 & process optimization

73 blocks

- Bridge
- Collapse or Pinching
- Pattern standing

Process window is improved by both material design and process optimization.

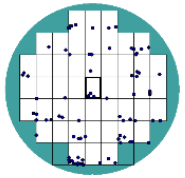
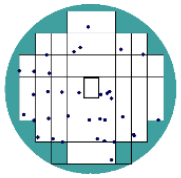
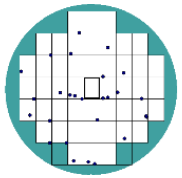
Rinse materials
EUV rinse – defectivity

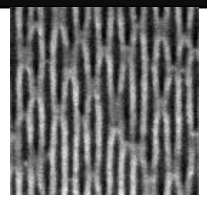
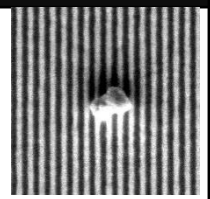
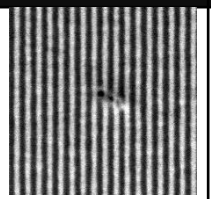
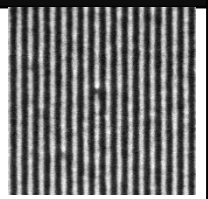
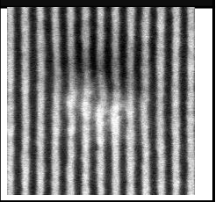


*[]: Defect count excluding invisible

Process conditions

Exposure tool: NXE3300 (0.33NA, Dipole)
EUV resist / 35nm thick (**18nm L/S**)
Dose / Focus: 40.5 mJ/cm^2 / -0.05um
Inspection area (Exposed area): 161.2cm^2

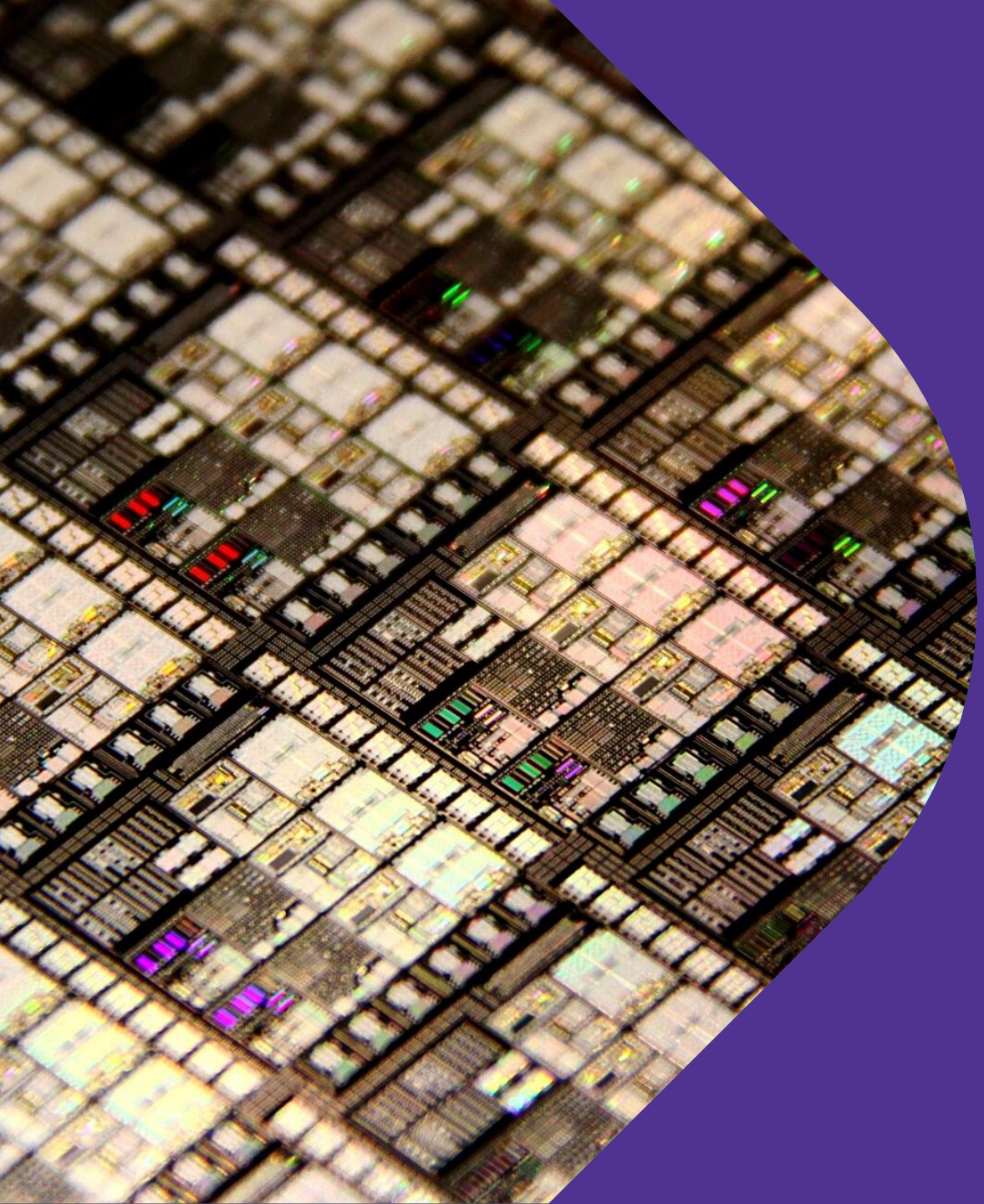
	DIW	Gen. 2	Gen. 3
Defect map			
Defect Density (pcs/cm2)	0.66	0.26	0.18

	Collapse	Fall on	Bridge	Pinching	Specific
Defect type					

- ✓ Pattern collapse dominates in regular process.
- ✓ Rinse process is effective in eliminating defects.
- ✓ Pinching defects are reduced with rinse process.

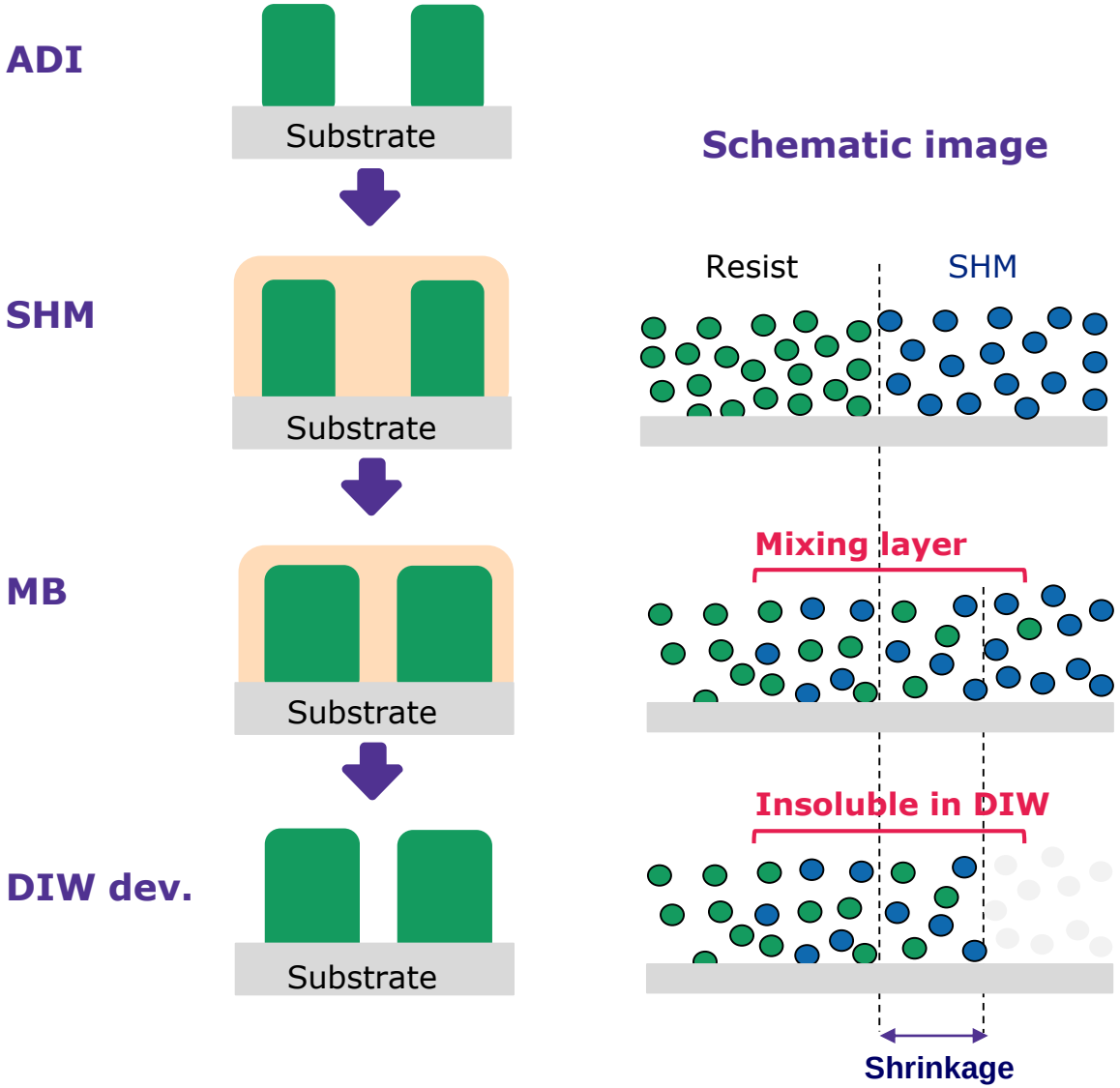
summary

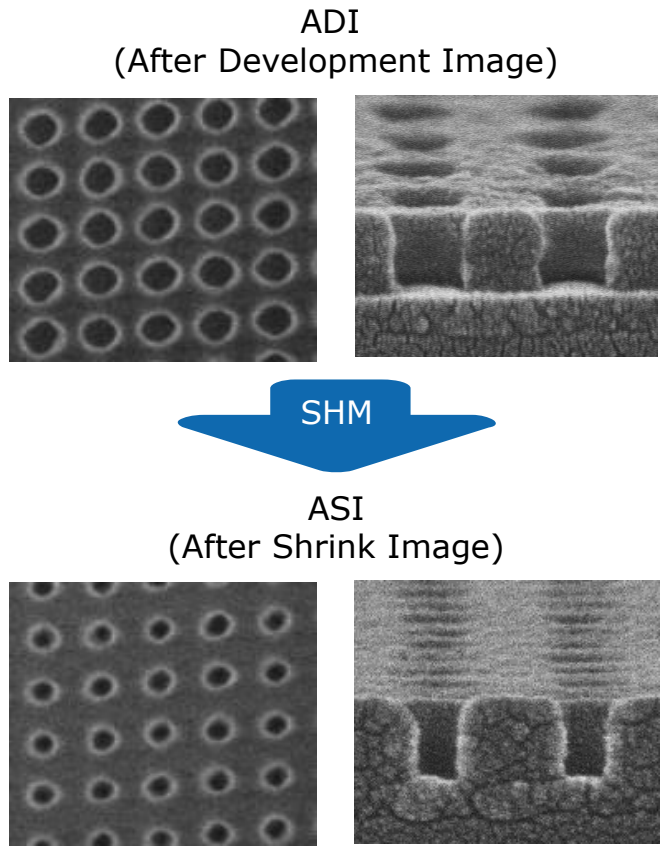
- **Rinse materials** offer benefits of pattern collapse mitigation and defect improvement, therefore, superior process margins for yield improvement.
- Merck offers rinse materials for both ArF and EUV lithography processes.
- Rinse process has been implemented in volume production of the first generation of EUV lithography.
- 16nm half pitch is resolved with rinse process with sufficient pattern collapse margin.
- Defectivity is significantly improved with EUV rinse.
- Collaborating with TEL, Merck offers not only innovative materials but also expertise in process optimization.



03 chemical shrink Materials

Shrink materials
The process & mechanism



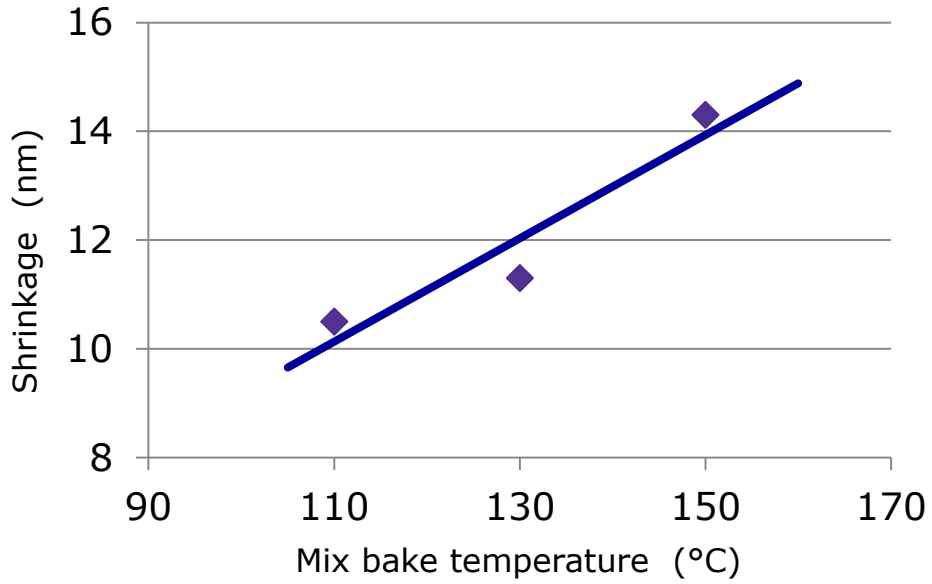


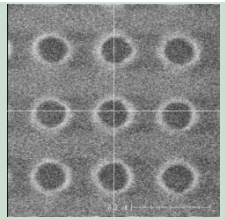
- Constant shrinkage through pitch
- Whole track compatible process
- In-process tunable shrinkage
- Reduced **C**ost **o**f **O**wnership

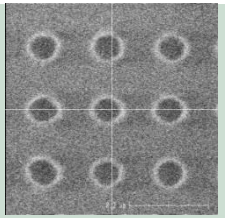
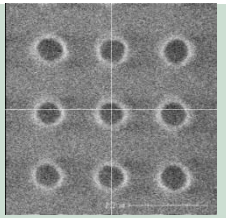
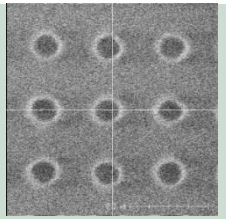
Shrink materials
Shrinkage controllability

Shrink Process

Film thickness:100nm
Mixing Bake: 110, 130, 150°C/ 60sec
Development: DI-Water



	ADI
Top Image	
CD (nm)	65.5

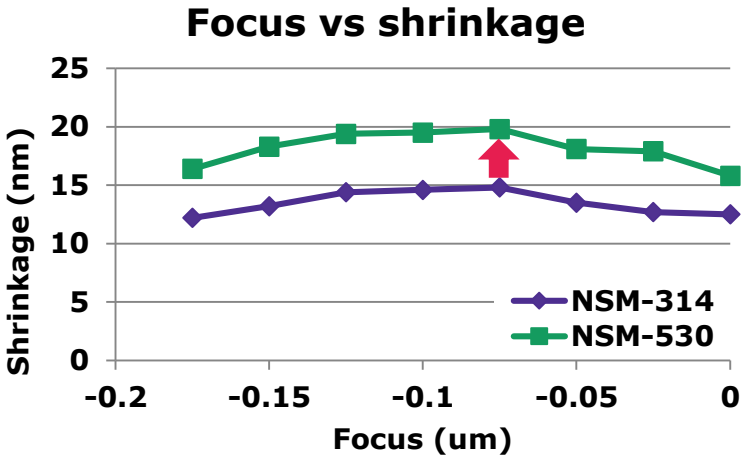
	110°C/60s	130°C/60s	150°C/60s
Top Image			
CD (nm)	55.0	54.2	51.2
Shrinkage (nm)	10.5	**11.3**	**14.3**

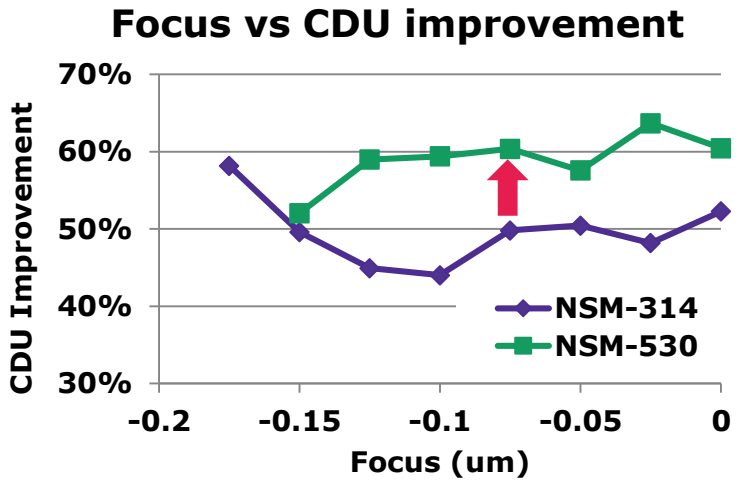
Shrink amount is tunable with mixing bake temperature.

Shrink materials
Local CD uniformity

Grid hole: 110nm pitch

Focus	−0.175 um	−0.150 um	−0.125 um	−0.100 um	−0.075 um	−0.050 um	−0.025 um	0.000 um
Control (ADI)								
StDev	2.51	2.46	2.56	2.34	2.65	2.38	2.45	2.2
CD	46.24	48.61	50.35	50.55	50.69	48.56	47.98	46.01
NSM-314 Shrink−D								
StDev	1.05	1.24	1.41	1.31	1.33	1.18	1.27	1.05
CD	34.02	35.46	35.97	35.94	35.91	35.08	35.27	33.56
Shrinkage	12.2 nm	13.2 nm	14.4 nm	14.6 nm	14.8 nm	13.5 nm	12.7 nm	12.5 nm
NSM-530 Shrink−D								
StDev	1.32	1.18	1.05	0.95	1.05	1.01	0.89	0.87
CD	29.88	30.28	30.96	31.06	30.93	30.51	30.13	30.23
Shrinkage	16.4 nm	18.3 nm	19.4 nm	19.5 nm	19.8 nm	18.1 nm	17.9 nm	15.8 nm



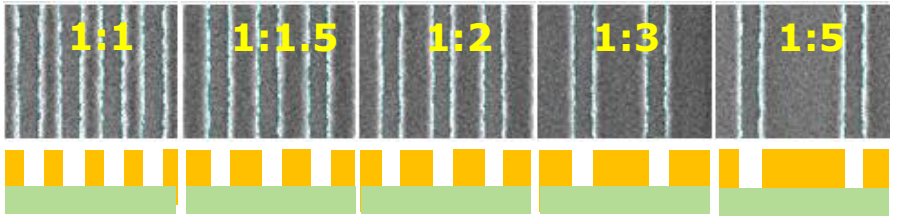


Local CD Uniformity is improved by >50%.

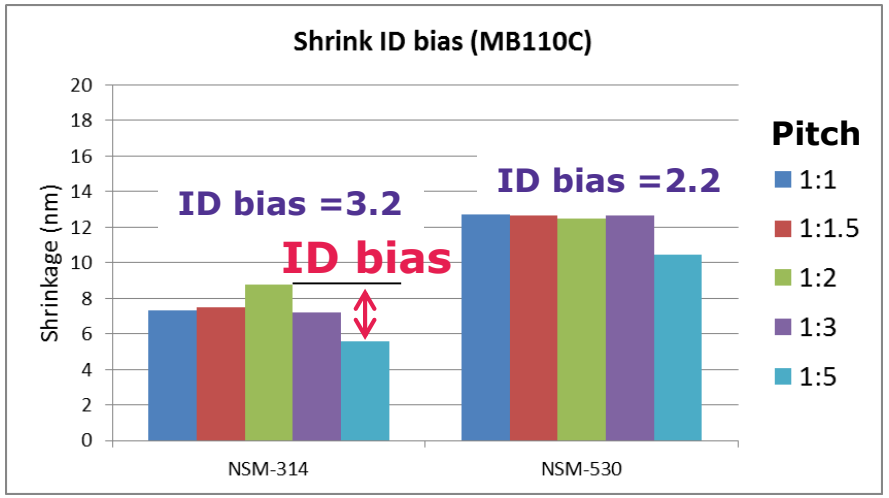
Shrink materials
Proximity effects

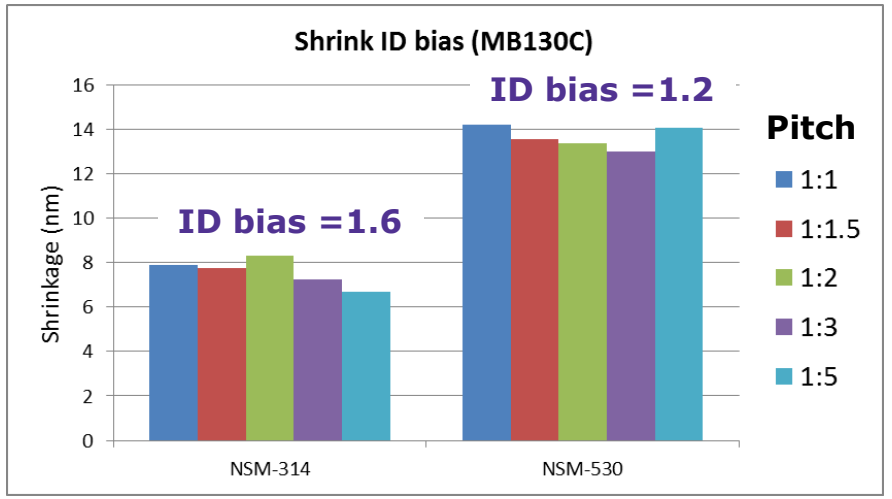
Test Conditions
NTD resist
Shrink Materials: NSM-314, 530
Mixing Bake: 110, 130°C / 60sec
Development: DI-Water

Resist Pattern Pitch



***ID bias = Isolated and dense pattern bias**

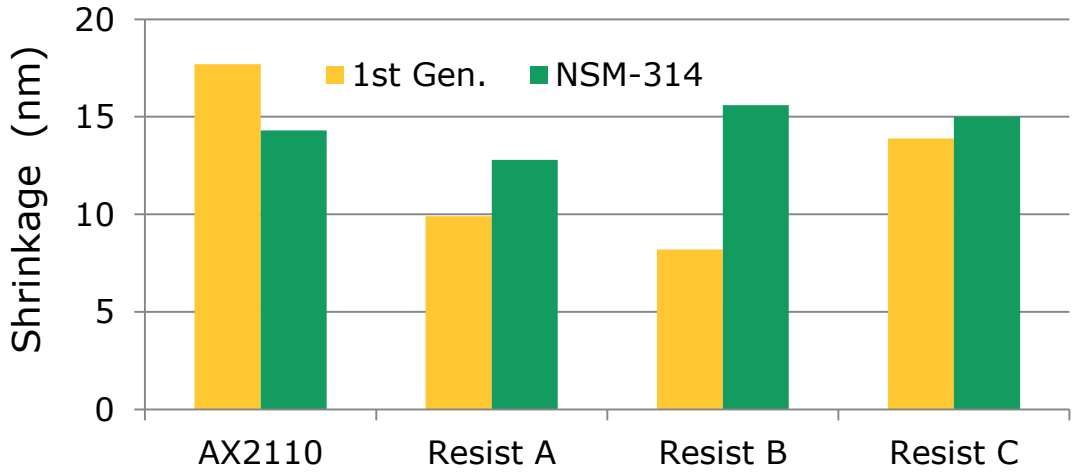


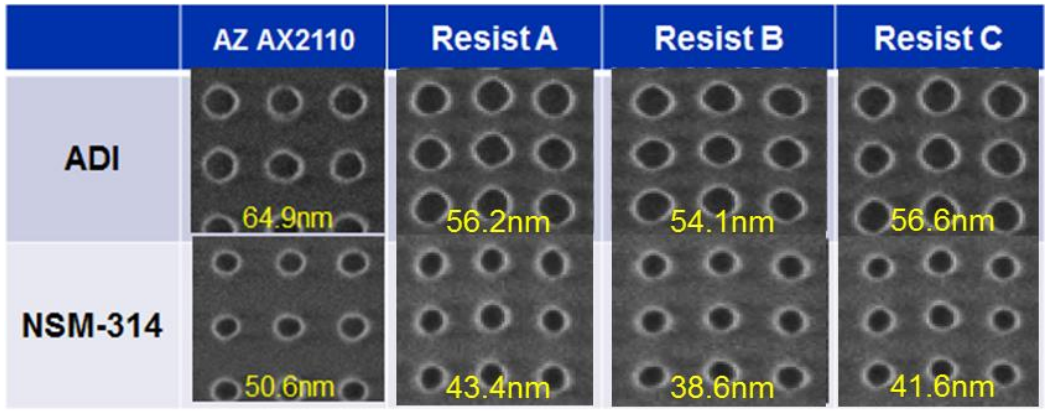


Significantly higher shrinkage and lower iso-dense bias are achieved with NSM-530.

Shrink materials
Resist compatibility

Test conditions
NTD resists from multiple suppliers
Shrink: 1st Gen shrink material and NSM-314
Mixing Bake: 150°C/60sec
Development: DIW





Good compatibility with various resists.

04 summary

summary

- Merck is specialized in **aqueous materials** to enhance photoresist performance.
- **Rinse process** has bee proven effective in mitigating pattern collapse, improving process margin, and depressing defectivity in multiple generations of lithography.
- **Chemical shrink** is a viable technology assisting pattern scaling with:
  - ✓ Cost-effective process enhancing resolution
  - ✓ Improvement of DOF & local CD uniformity with shrinkage tunable by process
  - ✓ Reduced proximity effects