Recent Progress in Dry Deposited and Dry Developed EUV Photoresist System

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on behalf of the Dry Photoresist Team at Lam

Office of CTO

Acknowledging with sincere gratitude contributions of imec and ASML

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Dry Deposited and Dry Developed EUV Photoresist System

- Dry photoresist manufacturability
  - Stability, tunability
- Holistic patterning optimization
  - Dose reduction
  - Defect reduction
- Pillar imaging using dry photoresist
  - Pillar stability and thickness scaling enabled by dry photoresist
- Dry photoresist processing at imec
- Summary

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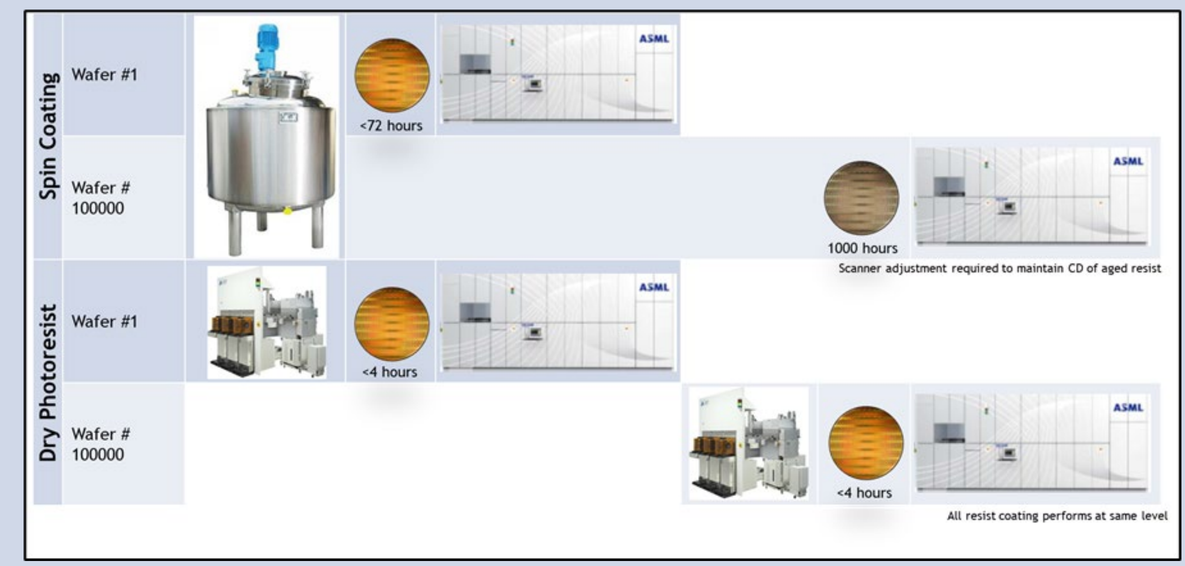
Benchmarking – Spin on vs Dry Photoresist

Dry photoresist relaxes stability requirements

- **Enhanced photosensitivity**
  - Dry photoresist can utilize higher sensitivity ligands due to relaxed shelf-life requirements
  - Spin on metal oxides limited stable ligands, issues include material degradation over time and batch-batch variation



- **Homogeneous, all material designed for photosensitivity**
  - Spin on materials contain stabilization agents, adhesion promoters
  - Dry photoresist contains *only* photosensitive materials, higher absorption of photons and improved selectivity during develop

Tightly spaced, small metal-organic units reduces blurring, higher photosensitivity

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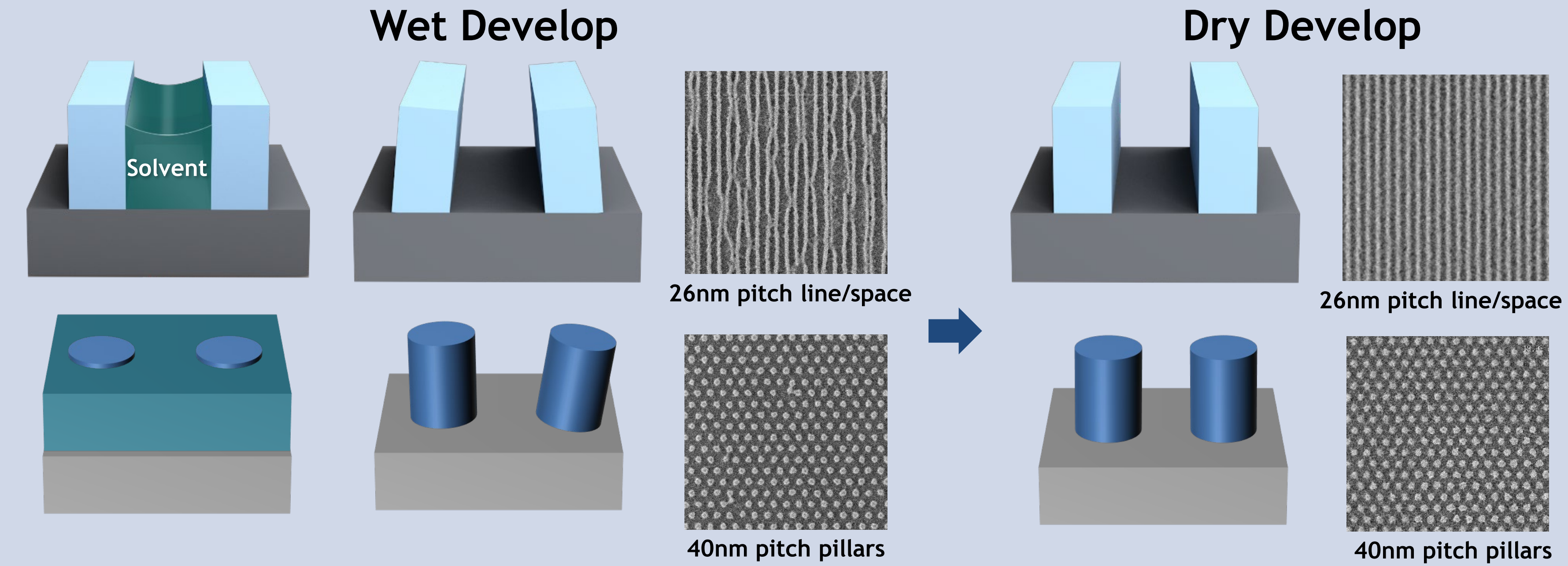
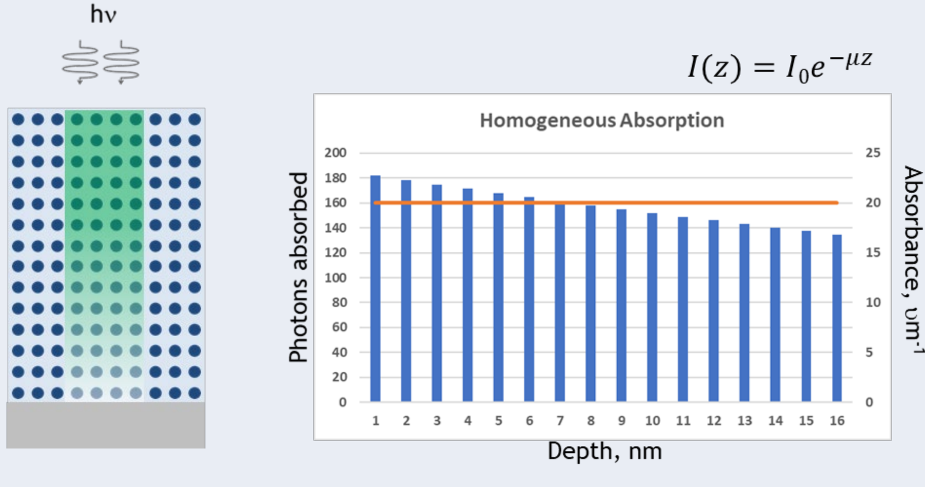
Benchmarking - Spin on vs Dry Photoresist

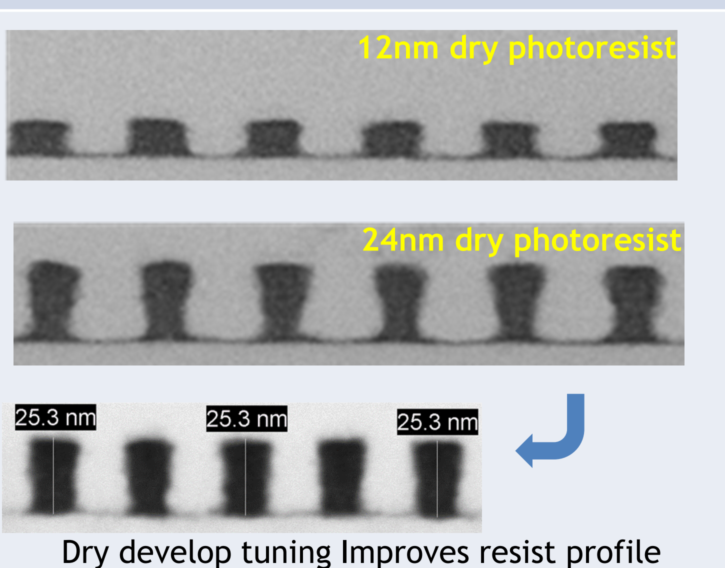
Dry photoresist has much larger defect free process window

- Dry develop improves line collapse margin
  - Solvent dry induces capillary forces and line collapse



- Dry develop enables thicker photoresist and higher total absorption





Dry develop tuning Improves resist profile

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EUV Dry Resist Enables *In-situ* Tuning → Faster Learning Cycles in R&D Phase

Vapor phase deposition, selective etch process conditions available for tuning

1st Cycle of Learning

Dry deposit - A → Metrology → EUV Exposure →

Dry Develop Tuning - "Selective Etch"

Dry develop process 1 → Metrology

Dry develop process 2…n → Metrology

2nd Cycle of Learning

Dry deposit - B → Metrology → EUV Exposure →

Metrology

Dry develop process 2…n → Metrology

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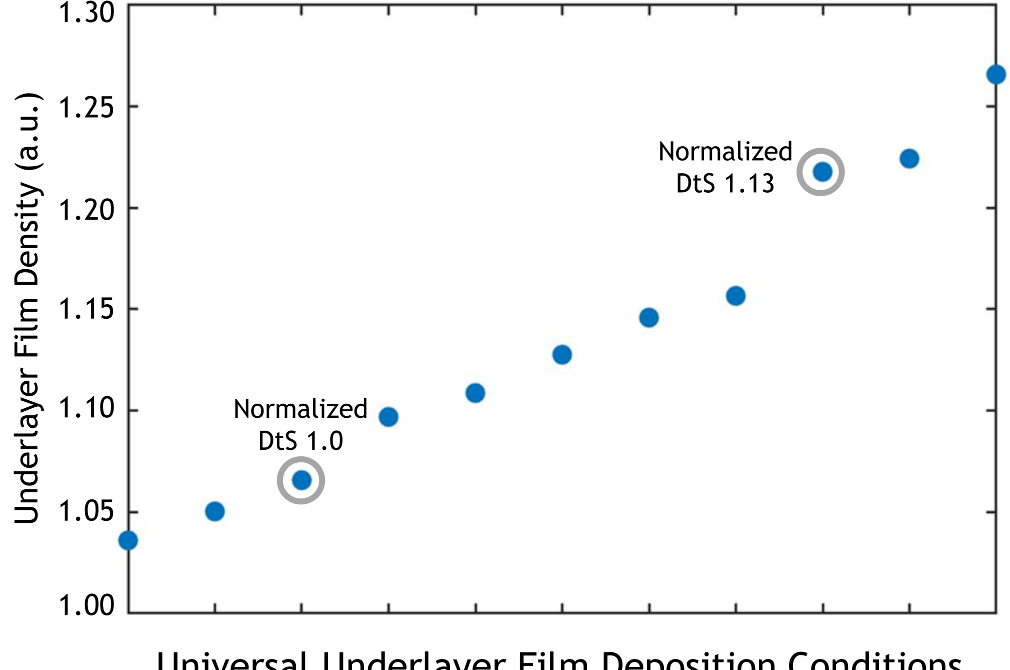
Integrated universal underlayer breaks dose and LWR tradeoff

Exposed at IMEC

Substrate	Dry PR on a-C	Dry PR on Lam Universal UL
DtS (mJ/cm^2)	62	52
Line CD (nm)	16.4	16.4
$LWR_{unbiased}$	2.9	2.9
IMEC Pitch 32nm		

25nm Dry PR
PECVD a-C

25nm Dry PR
Lam Universal UL
PECVD a-C



Integrated co-optimized universal underlayer delivers significant (>16%) DtS reduction

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EUV Dry Resist: Dry Development Enables Tunability of Resist Pattern

Dry resist CD tuning with dry development conditions for pitch 28nm L/S

IMEC NXE 3400
P28nm Line/Space
PR over a-carbon

- Dry development parameters such as temperature and pressure can be optimized *in-situ*
- Faster cycles of learning to tune CD, resist profile and to minimize LWR

Dry Develop Process	Baseline	Modified	Enhanced
CD SEM			
Cross-section TEM			
Pitch (nm)	28	28	28
Line CD (nm)	15.0	14.0	13.4
$LWR_{unbiased}$ (nm)	3.1	2.9	2.9

LWR=Line width roughness, CD=Critical dimension, X-section = Cross-section, SEM=Scanning Electron Microscopy, TEM=Transmission Electron Microscopy

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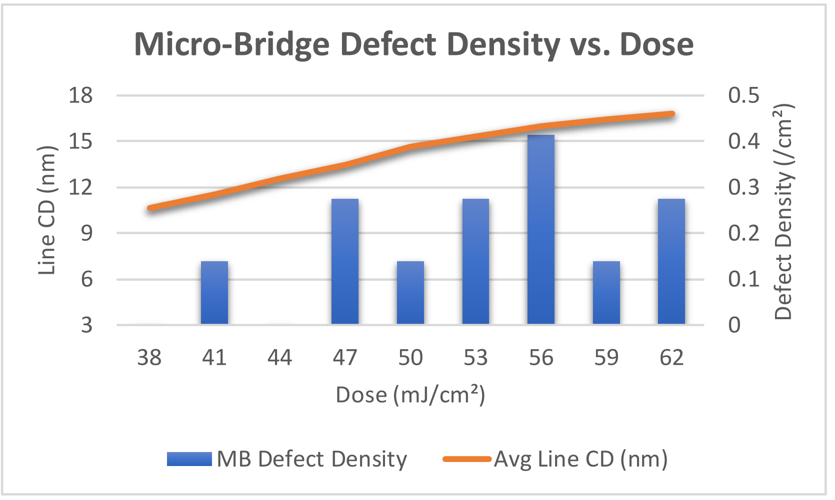
Holistic Approach to EUV Patterning of Pitch 32nm

Further improve LWR by >20% with Lam film stack and transfer etch

Exposed at IMEC

	Dry Development	a-C HM Open	TiN HM Open	Strip / Clean
Pitch	32nm	32nm	32nm	32nm
CDSEM				
Cross-section	a-C HM SiOx TiN SiOx			
Line CD	15.8	14.9	15.4	15.8
$LWR_{unbiased}$	2.9	2.6	2.6	2.2
Process	imec NXE-3400 / dry development / Lam pattern transfer			



- Dry development enables large microbridge process window
- No line break defect with thicker PR

Dry development enables large microbridge process window

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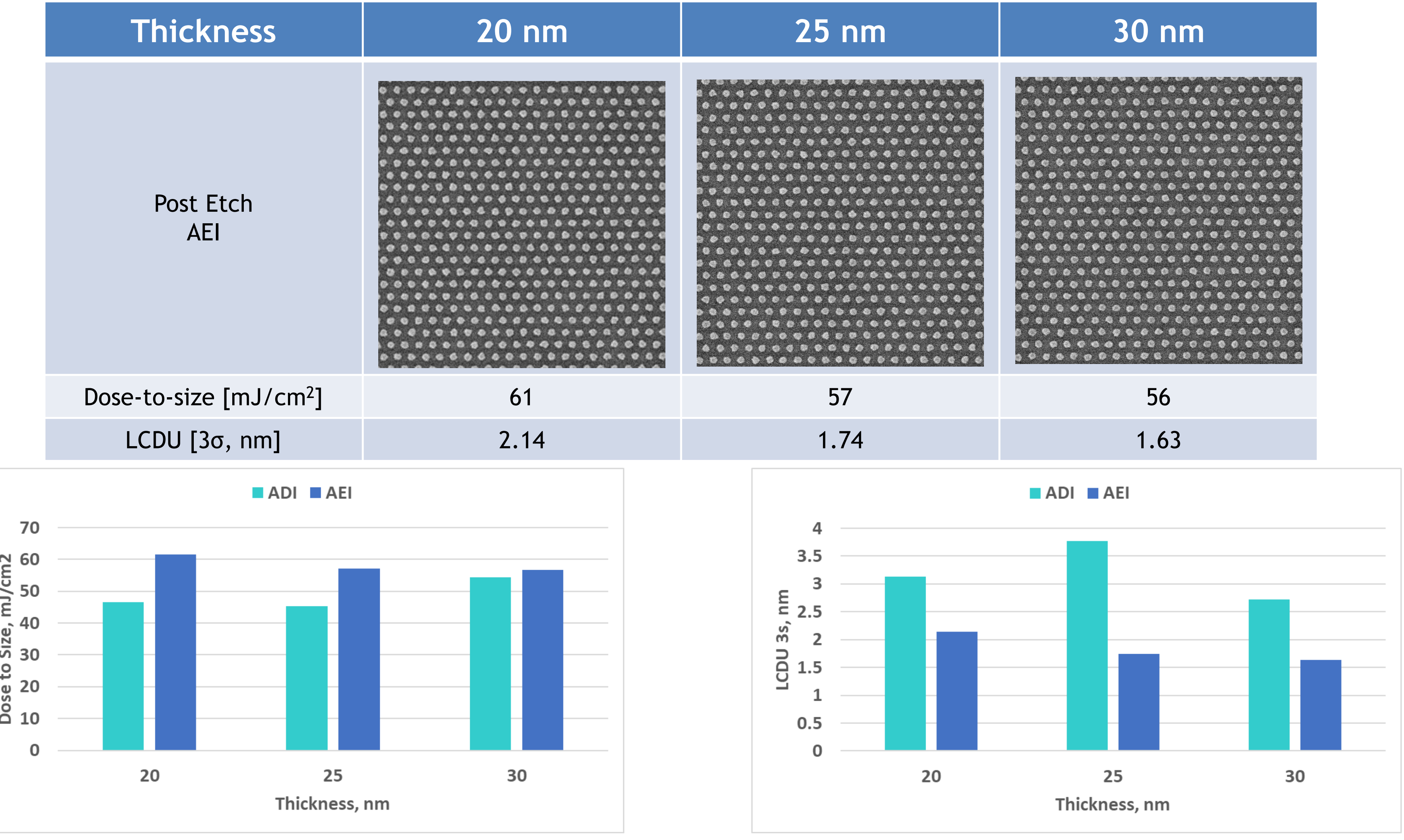
P40x70 Pillars – Dry resist in-situ tuning

Thickness optimization improves dose and LCDU

Exposed at ASML



Thickness	20 nm	25 nm	30 nm
Post Etch AEI			
Dose-to-size [mJ/cm^2]	61	57	56
LCDU [3σ, nm]	2.14	1.74	1.63

Thicker photoresist enables lower LCDU (~25%)

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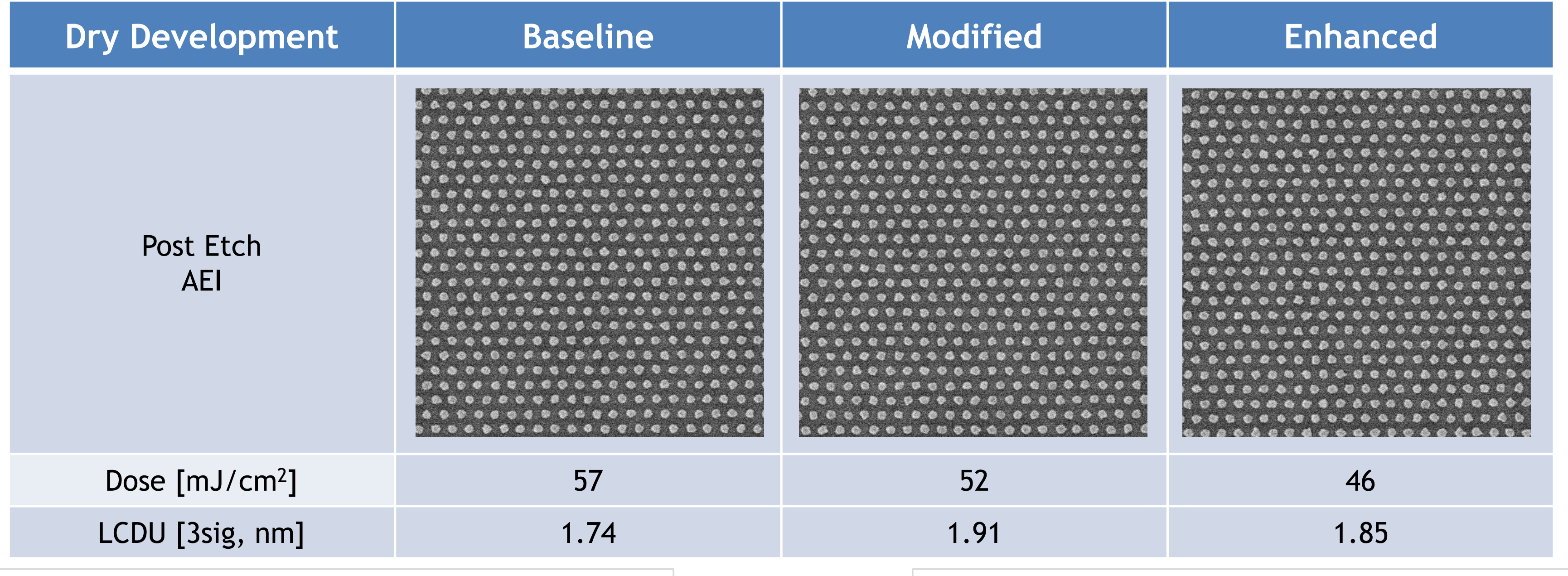
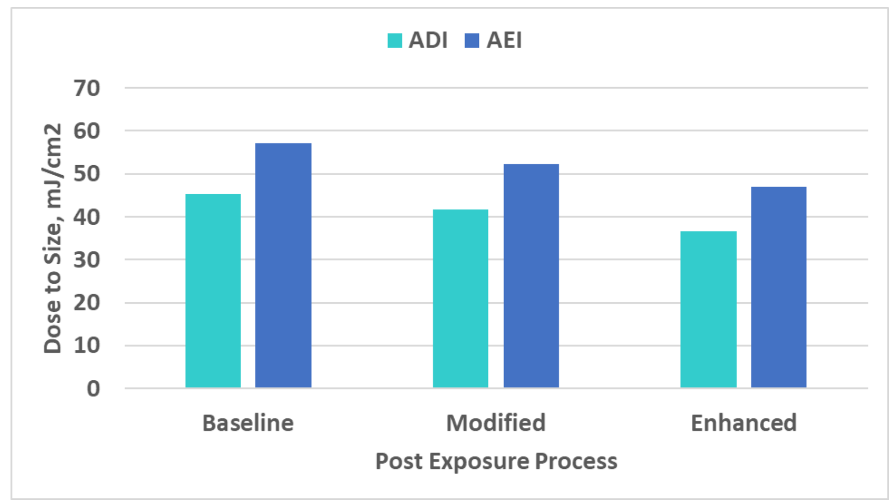
P40x70 Pillars – Dry resist process tuning

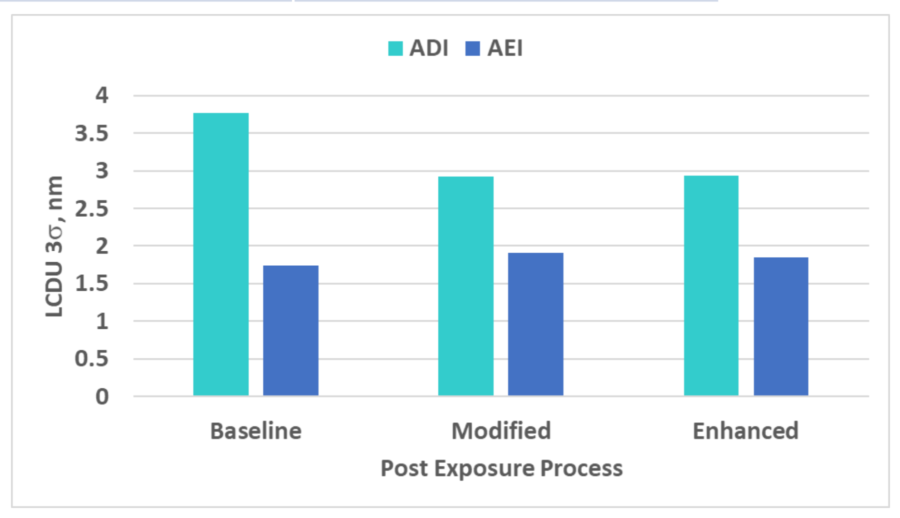
Co-optimization of dry development with post exposure bake conditions

Exposed at IMEC



Dry Development	Baseline	Modified	Enhanced
Post Etch AEI			
Dose [mJ/cm^2]	57	52	46
LCDU [3sig, nm]	1.74	1.91	1.85





Co-optimization of PEB and dry development improves DtS (~20%)

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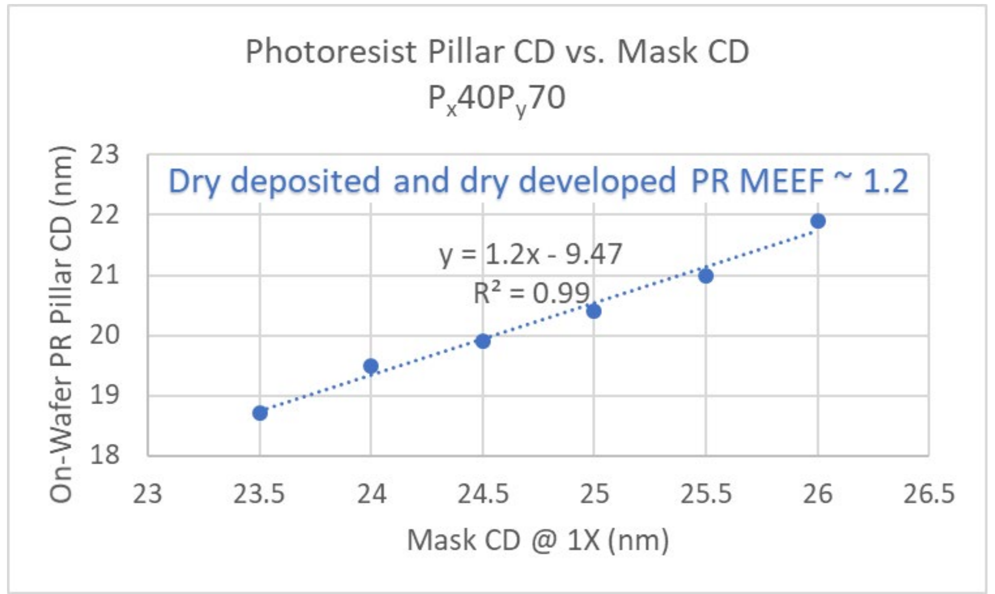
Low MEEF for P_x40-P_y70 pillars

Exposed at IMEC

P_x40P_y70	Mask CD 23.5	Mask CD 24.0	Mask CD 24.5	Mask CD 25.0	Mask CD 25.5	Mask CD 26.0
Dose 65 mJ/cm²	CD 18.7nm	19.5nm	19.9nm	20.4nm	21.0nm	21.9nm



Pillars P_x40-P_y70 patterned with dry develop show low MEEF ~1.2

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Dry Photoresist Deposition and Dry Develop Tool Installed / Qualified at IMEC

EUV dry resist tool at imec

Criteria	Spec Value	Results at imec
Resolution (Pitch L/S)	≤32 nm	<26 nm
Dose (P32)	≤ 50 mJ/cm^2	<47 mJ/cm^2
LWR (ADI)	<3.0 nm	2.7 nm
LER (ADI)	≤2.3 nm	2.0 nm
WiW CDU (3σ)	≤1 nm	0.3 nm

	25nm Dry PR on α-C
Pitch	32nm
Dose	46.9 mJ/cm^2
Wafer CD Map	Mean : 15.7 nm 3-sigma: 0.3 nm (1.7 %) Range : 0.4 nm (2.2 %)
Line CD	15.7 nm
LWR_{unbias}	2.7 nm
CDU (3σ)	0.3 nm
Wafer CD Range	0.4 nm

LWR=Line width roughness, LER=Line edge roughness, ADI=After development inspection, WiW=Within wafer, CDU=Critical dimension uniformity, α-C = amorphous carbon

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Summary: Dry Deposited and Dry Developed Photoresist for EUV Patterning

- **EUV dry resist offers a high-resolution, lower-defectivity, and greener solution for (pitch≤32nm L/S, pitch≤40nm pillar) EUV patterning in the fab.**
- **EUV dry resist technology offers versatile *in-situ* tuning knobs for faster cycles of learning.**
- **EUV dry resist technology has been validated by dose-to-defectivity and process stability.**
- **Lam EUV dry resist tools have been installed and qualified at imec**
  - Suite of Lam tools including hard-mask deposition and pattern transfer etch will be used for process integration research at iN3/iN2 and beyond.

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