Metal Oxide Photoresists:
Unlocking the Full Potential of EUV Patterning

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Inpria[1], IMEC[2]
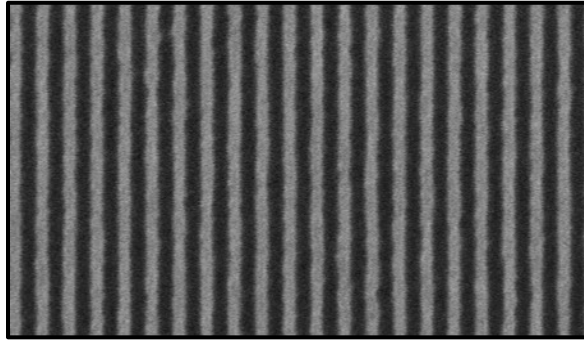
Inpria Resist Design Principles

Photocondensed
Molecular
Metal Oxides

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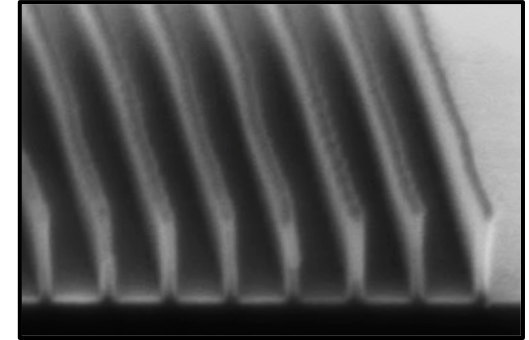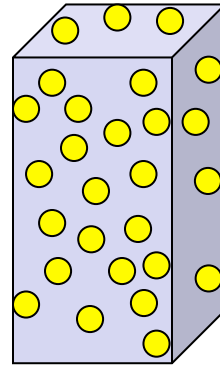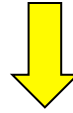
Inpria Approach: Tin Oxide Based Resist

5X smaller molecular building blocks

5X more photons absorbed / volume

>10X higher etch selectivity
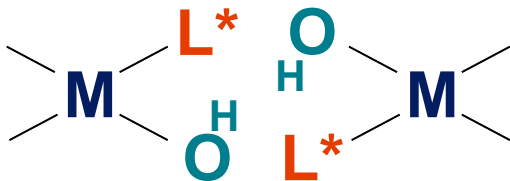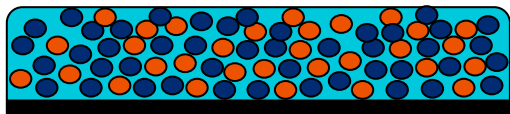

11nm half-pitch (Inpria)

Enables high resolution & low LWR patterns

Path to lower doses at high resolution

Improved pattern collapse & process simplification
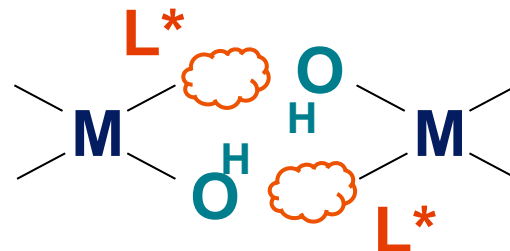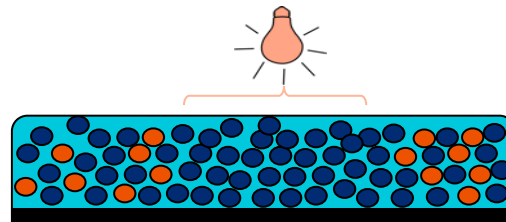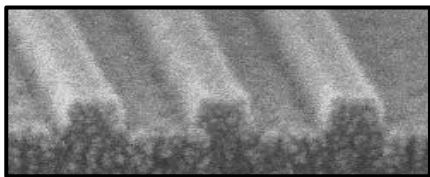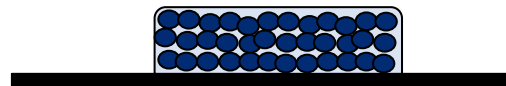
Inpria's Patterning Mechanism

Metal oxo-hydroxo clusters

L* = radiation sensitive ligand

Cluster size ~1 nm

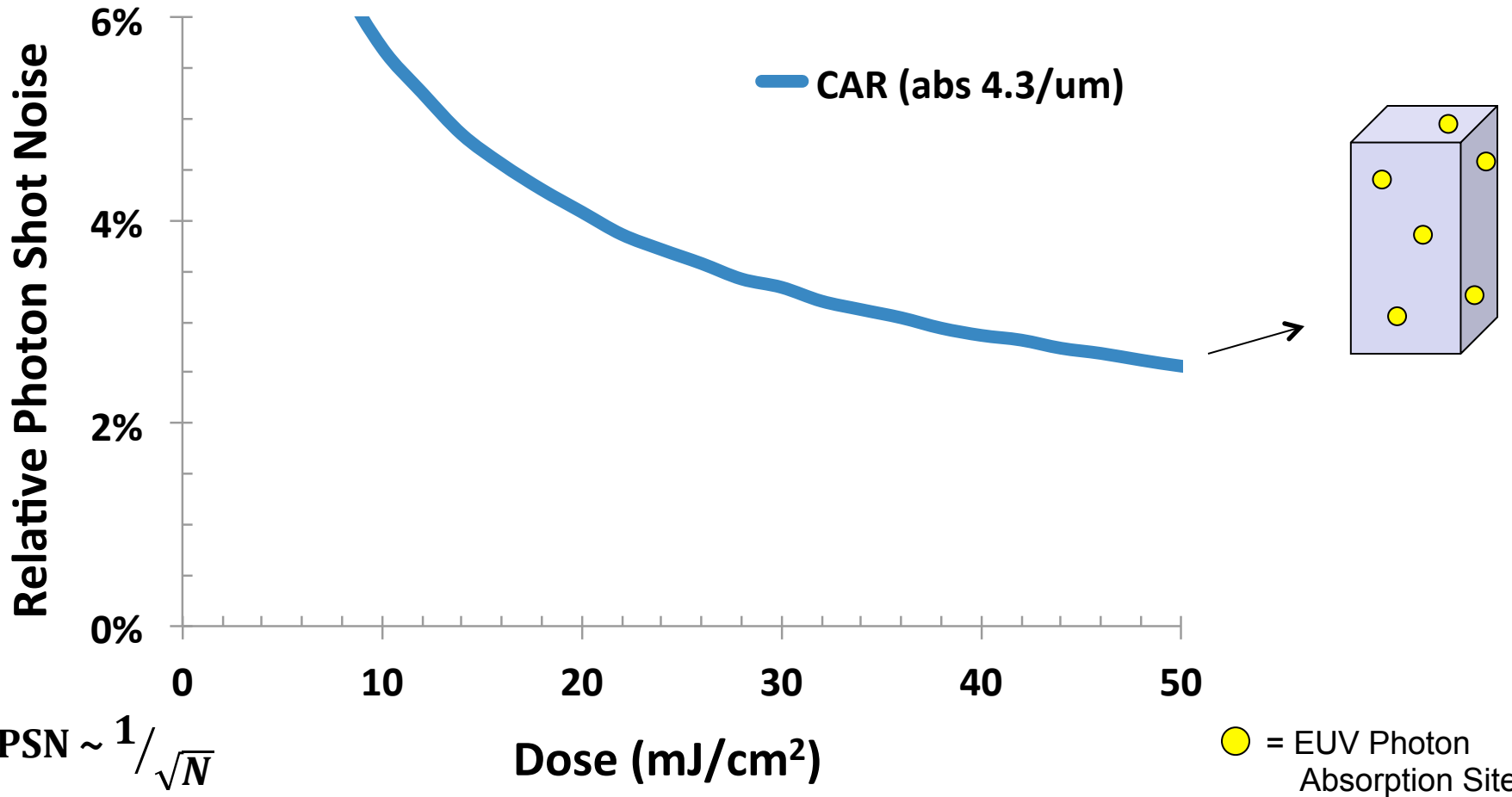Bake & Develop

Patterned film

Photocondensed molecular metal oxide

$+ H_2O$, L*

Negative tone: organic developer

Design in Photon Shot Noise Regime

Relative Photon Shot Noise vs Dose (mJ/cm²). Legend: CAR (abs 4.3/um).

$PSN \sim \frac{1}{\sqrt{N}}$

⬤ = EUV Photon Absorption Site

Prolith simulation: 20nm x 20nm sq, 30nm resist thickness (courtesy John Biafore, KLA-Tencor)

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Design in Photon Shot Noise Regime

Prolith simulation: 20nm x 20nm sq, 30nm resist thickness (courtesy John Biafore, KLA-Tencor)
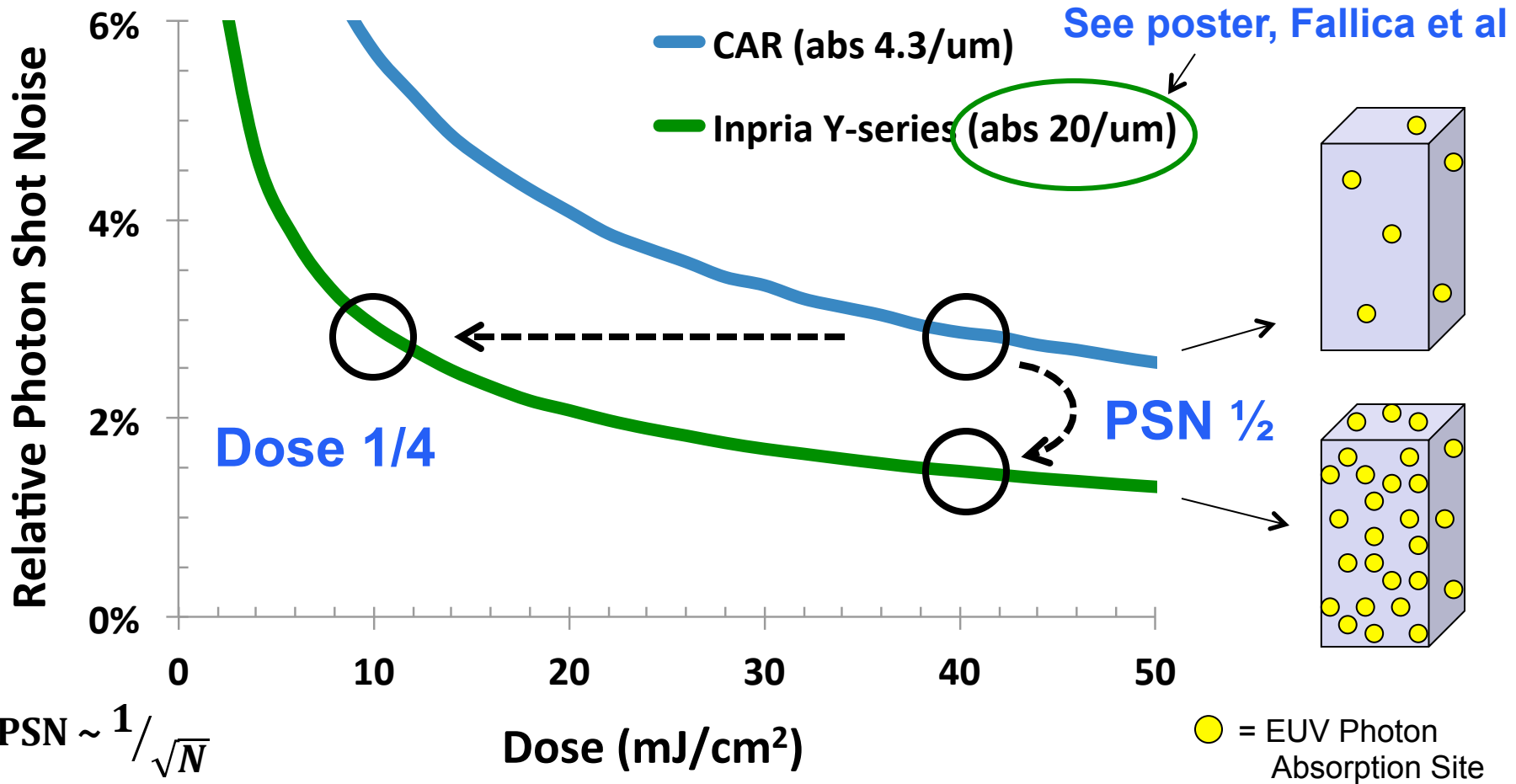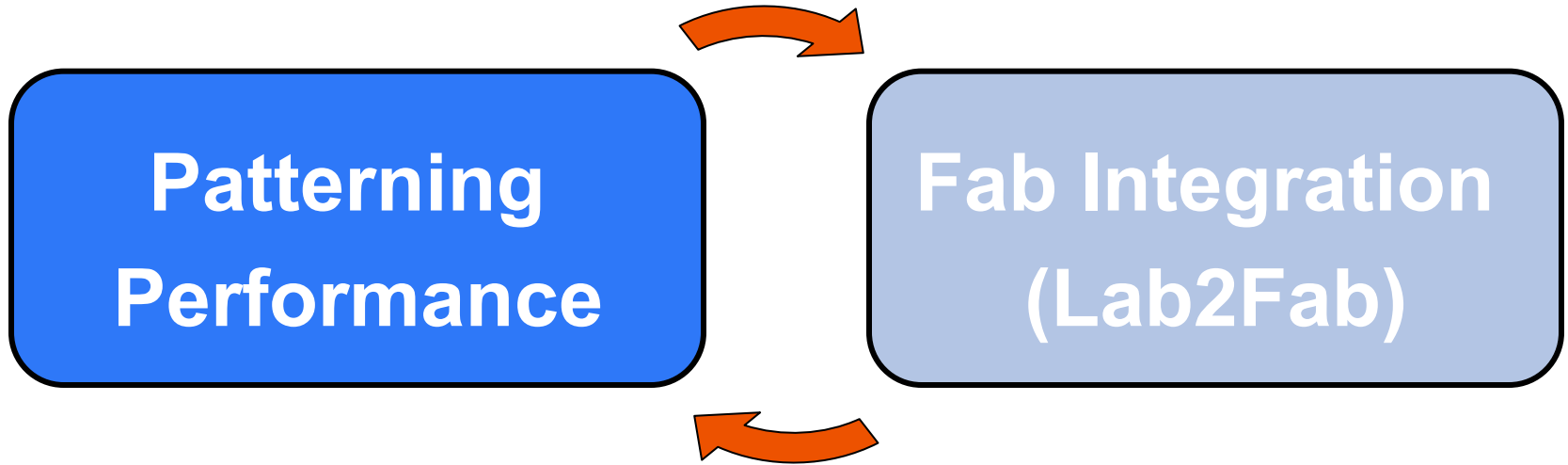
Gen 2 Platform Development

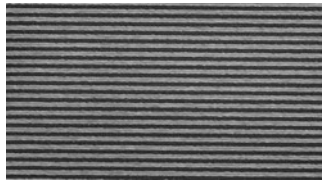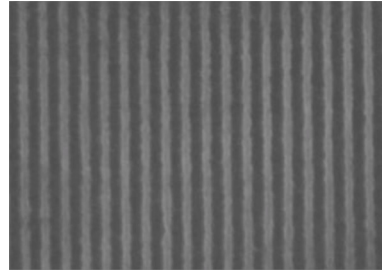| 1Q14	2Q14	3Q14	4Q14	1Q15	2Q15	3Q15	4Q15

YA-AA
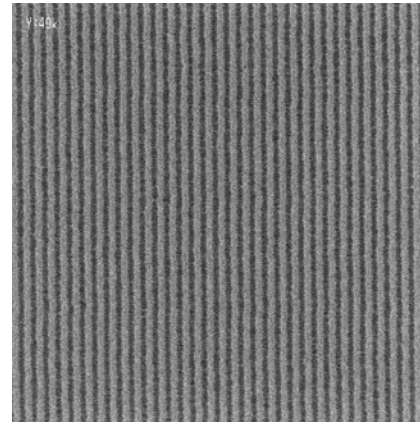
22nm HP: ~90 mJ/cm^2
(microfield exposure)

YA-BA

17nm HP: 40 mJ/cm^2
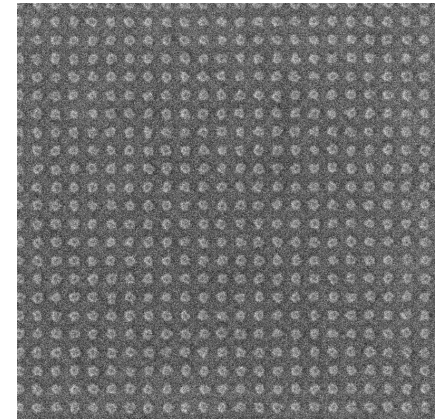(microfield exposure)

YF-AA

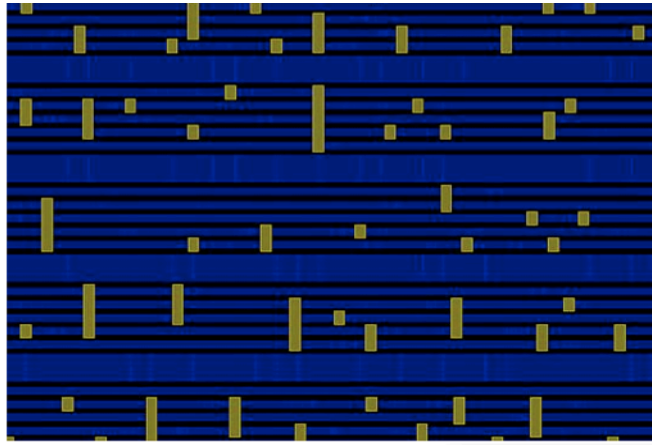13nm HP: 35 mJ/cm^2
(NXE:3300 scanner)

YF-BH

18nm 22P36: 33mJ/cm^2
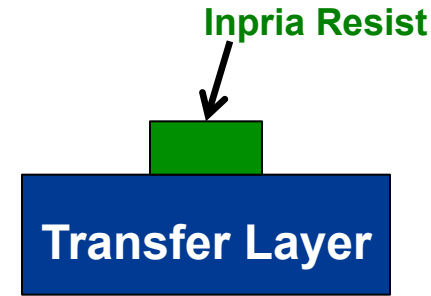(NXE:3300 scanner)

Pushing RLS
Moving to N7 2D patterning

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IMEC N7 Metal Block Layer

3 193i Masks ➡ **1 EUV Mask**

CA Resist

Tone reversal module

Transfer Layer

Current EUV

Inpria Resist

Transfer Layer
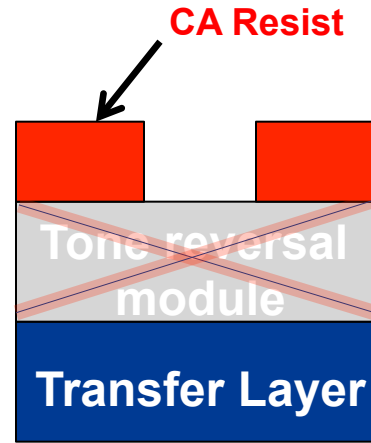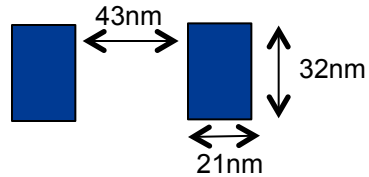
Inpria EUV

Current EUV scheme:
    Positive tone resist
    Tone reversal in process
        (multiple etch/dep steps)
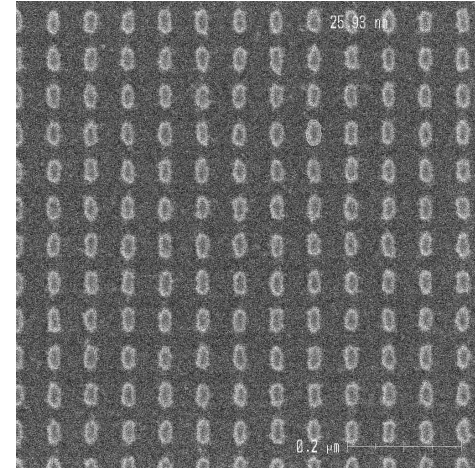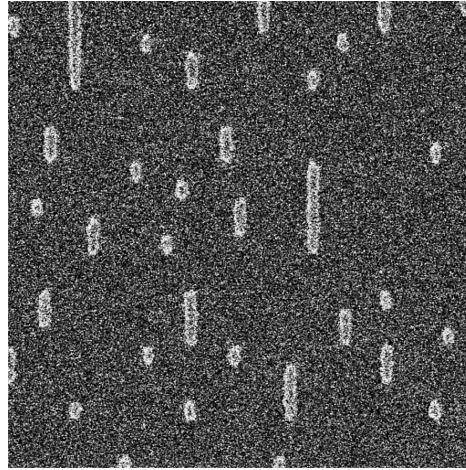   Pattern transfer

Inpria scheme:
    Negative tone resist
    Pattern transfer

    Process simplification
    Cost reduction

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NXE3300 Block Mask Pattering

N7 Min Feature

43nm

32nm

21nm

IMEC N7 Block Mask Pattern – No Bias/OPC

Dose to size: 33 mJ/cm^2

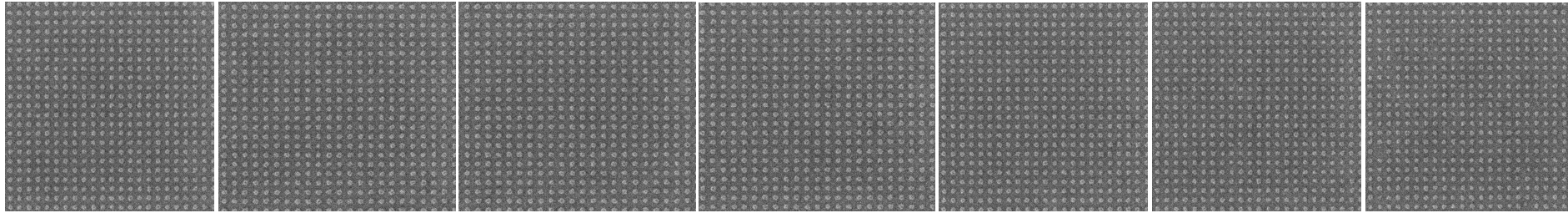EL_{max}: 29%, DOF@10%EL: 169 nm

18nm Half Pitch Dots

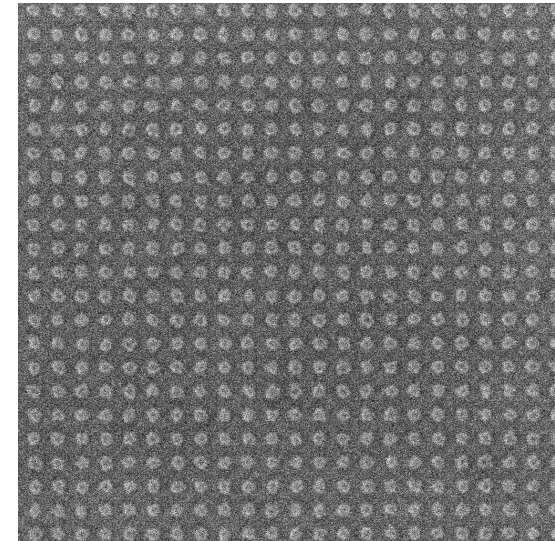-75nm　-50nm　-25nm　0nm　25nm　50nm　75nm

22P36 exposed to 18nm

Quasar Q30 0.9/0.6

Dose to size: 33 mJ/cm^2

EL_{max}: 18%, DOF@10%EL:150 nm

LCDU 3σ: 2.8nm

Extendibility: Resolution Headroom

100nm

9.5nm lines on 20nm pitch, LWR 1.8nm, ~50mJ/cm^2
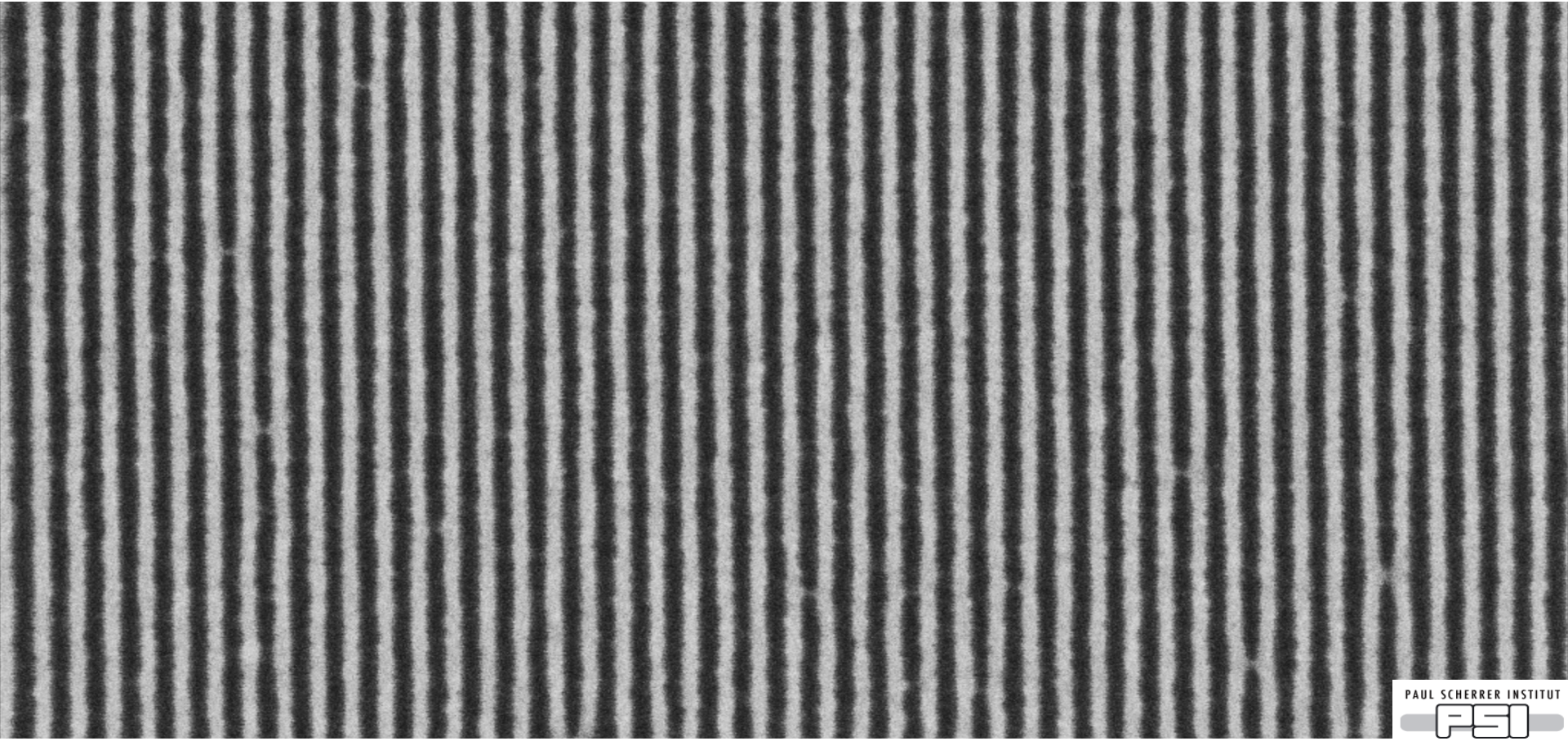
Target readiness for N7 insertion

Patterning Performance ⇄ **Fab Integration (Lab2Fab)**

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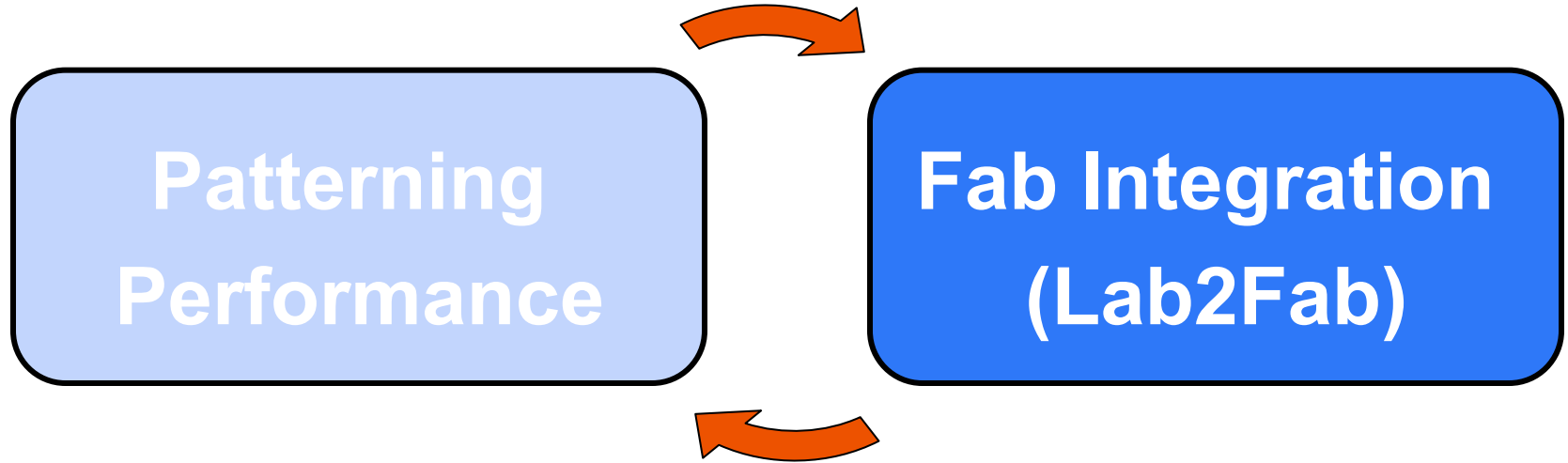
N7 Fab Integration

- Resist Stability
- Metal X-Contamination
- Litho Process Optimization
- Develop Pattern Transfer & Integration Scheme
- Build Models (Resist/OPC)

Resist Stability

Resist Age vs. Dg (mJ/cm^2)

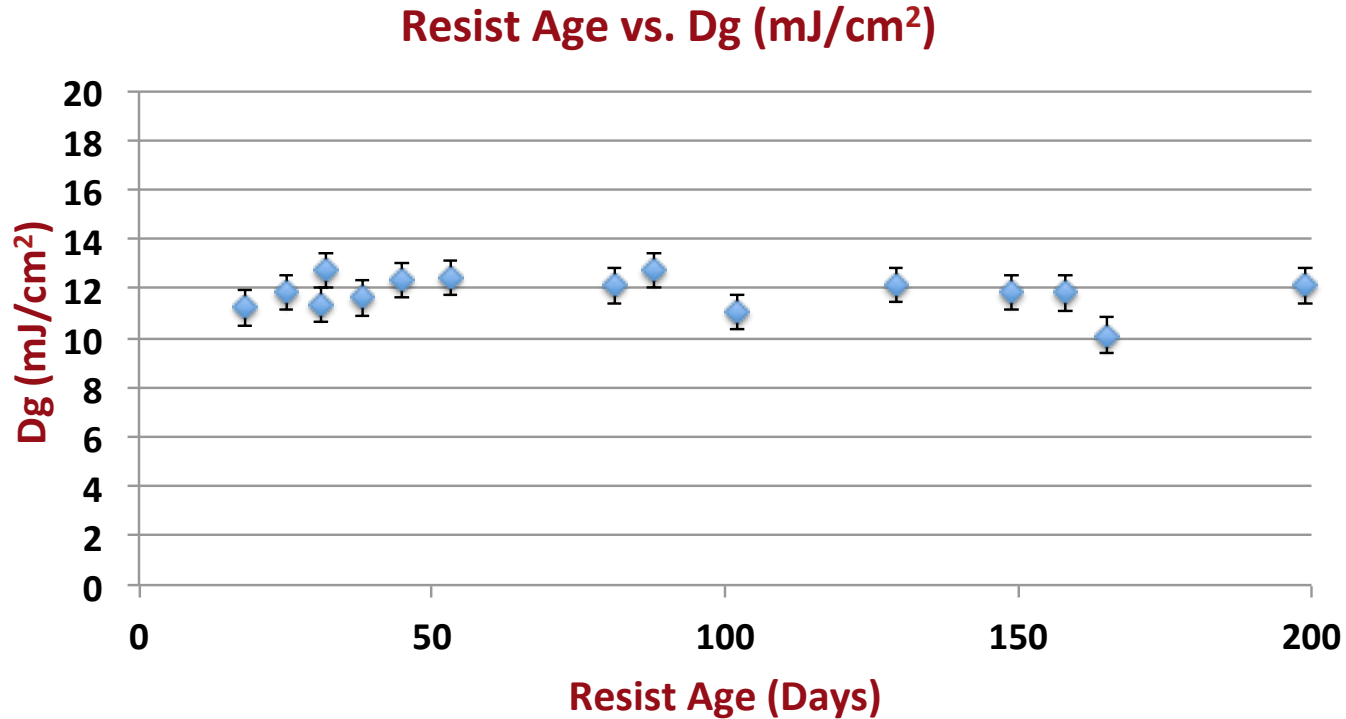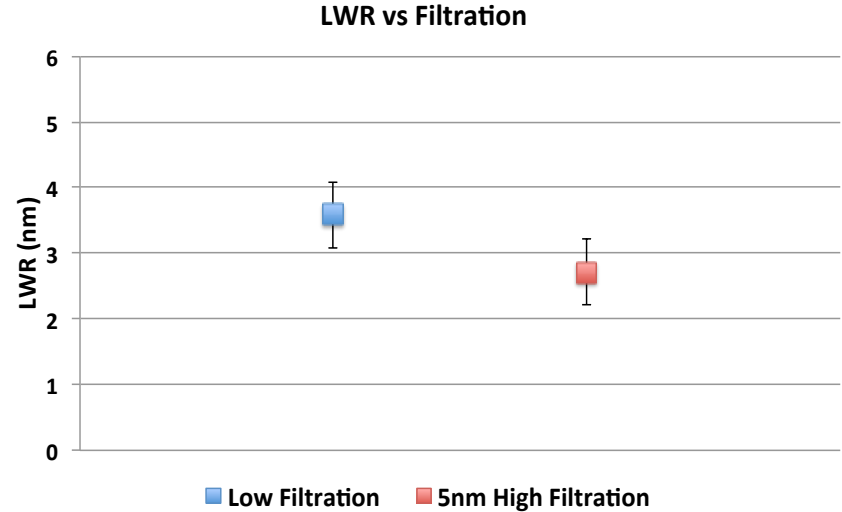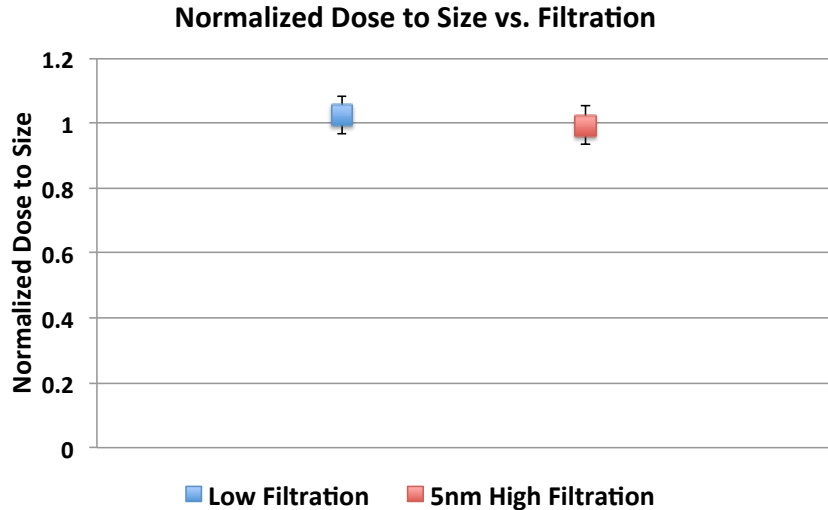Resist stored at room temp shows good dose stability through 200 days

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Effect of Filtration

Normalized Dose to Size vs. Filtration


LWR vs Filtration

■ Low Filtration ■ 5nm High Filtration

Objective: Demonstrate Inpria EUV Photoresist compatibility with state-of-art filtration.

Experiment: Do a recirculating filtration of the resist with a 5nm Entegris filter, until particles measure <3 counts/mL, measure E_{size} at LBNL BMET and compare to resist filtered with >20nm pore size

No impact on litho performance with 5nm aggressive filtration

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Entegris

Metal X-Contamination
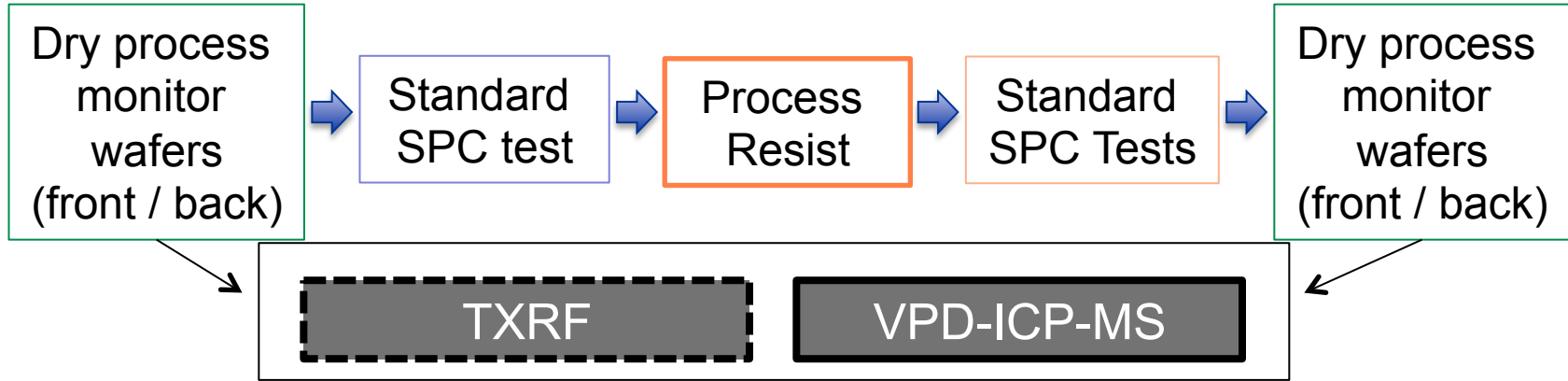
Qualifying process equipment for use with Inpria metal containing resists
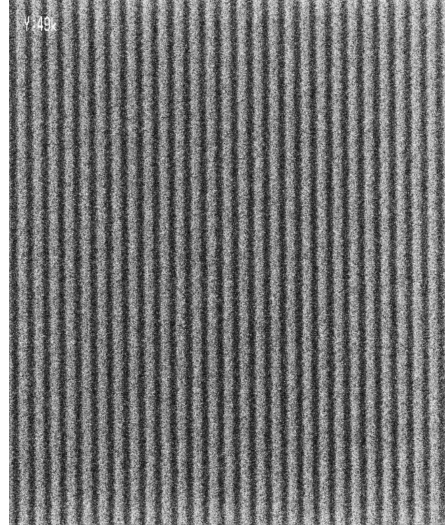
- Track
    - 100 wafer test on SCREEN ✔
    - 50 wafer test on TEL ✔

- Etchers
    - TEL & LAM etchers ✔

- **ASML granted waiver for 100 full-wafer-equivalents on all NXE3300's** ✔
    - limited waiver granted with assessment towards unlimited waiver ongoing
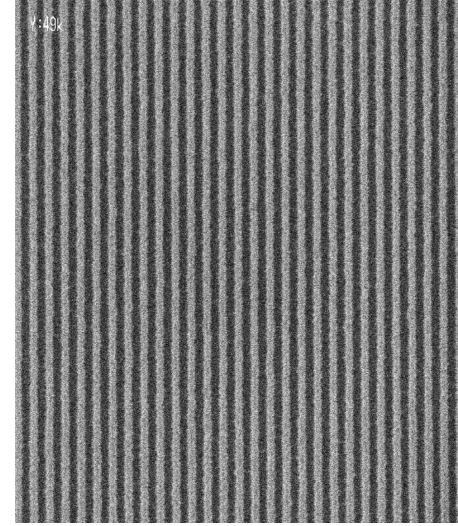
Under Layer Compatibility

**NXE3300 16nm L/S – Dipole 90x**
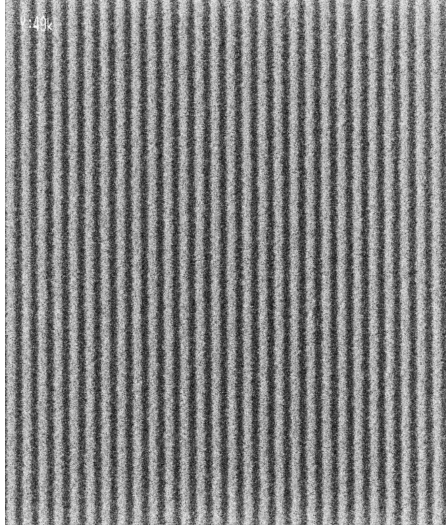
| Under Layer | SOG | SOC |

- Evaluated compatibility of standard EUV under layers, SOG's, SOC's
- Showing equivalent process windows (%EL, DOF, LWR)
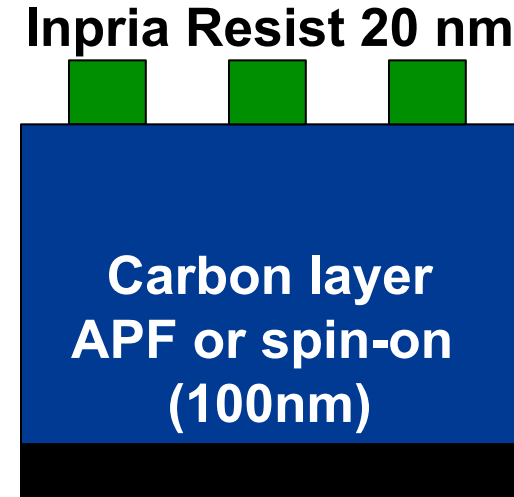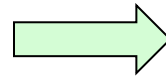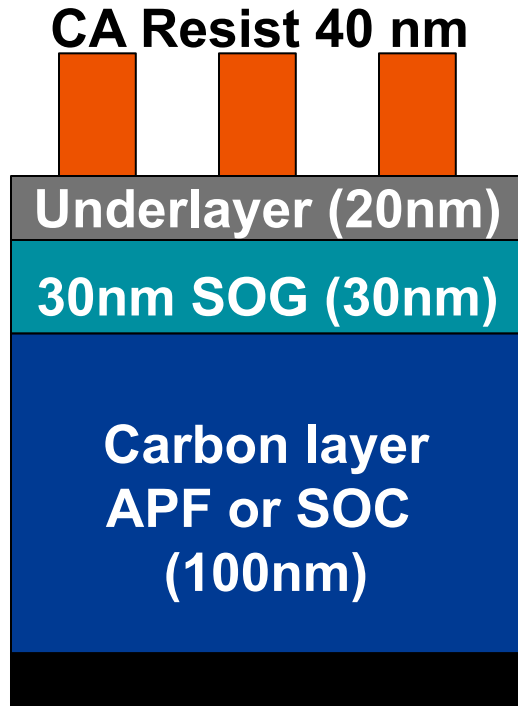- Only one material from one vendor showing issues due to incompatibility with the NTD organic developer

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Etch Rates

Etch step type	Etch chemistry
BARC opening	Cl2/O2
UL opening	CF4/O2/CH2F2
SOG opening	Cl2/O2/N2
SOC opening	SF6/N2/CH2F2/He

Resist Etch Rates vs. Chemistry
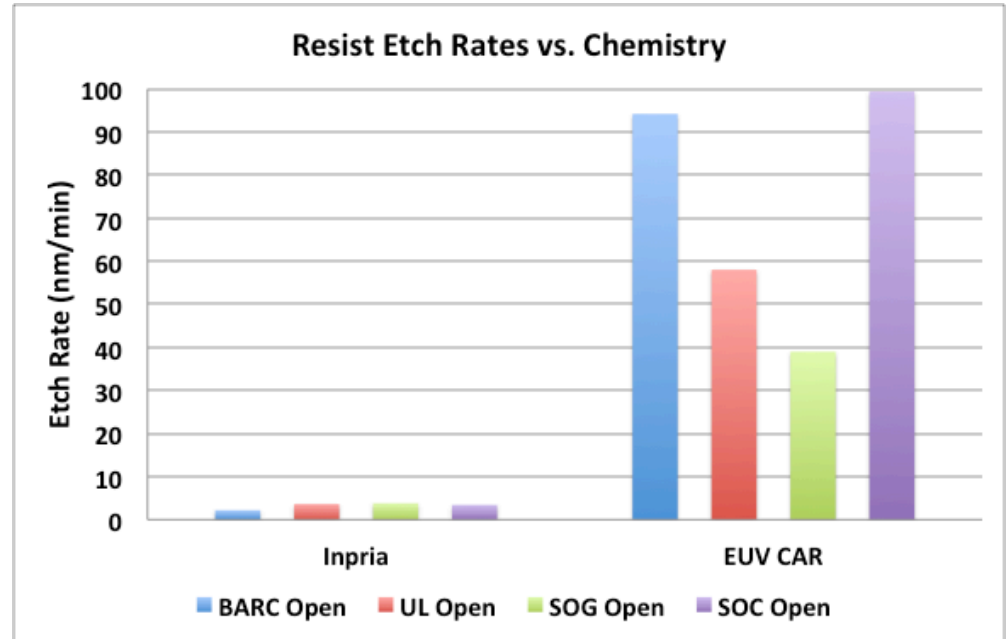
- Inpria shows significantly better etch selectivity than EUV CAR

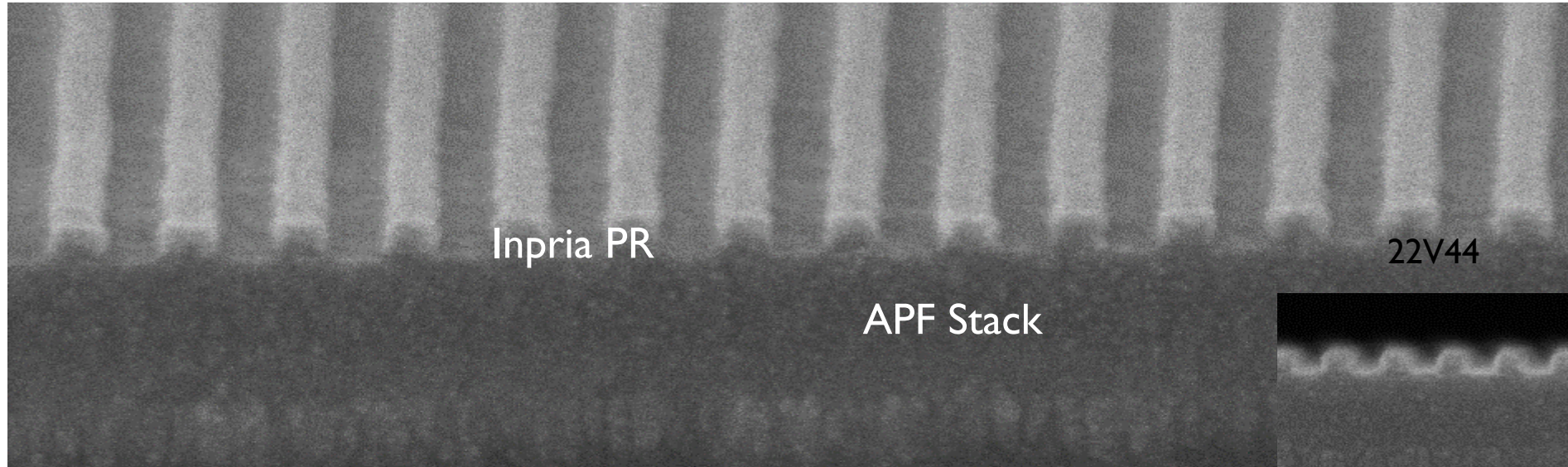- Selectivity to SOC is 1:40 which opens up paths to simplified process schemes

Simplified EUV Pattern Transfer

- Mitigates pattern collapse
- Saves dep & etch steps
- Reduces process time
- Cost of ownership reduction

CA Resist 40 nm

Underlayer (20nm)

30nm SOG (30nm)

Carbon layer
APF or SOC
(100nm)

Tri Layer

Inpria Resist 20 nm

Carbon layer
APF or spin-on
(100nm)

Simplified Stack

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Pattern Transfer

Inpria PR

APF Stack

22V44

Inpria 22nm L/S pattern on APF stack
Imaged on NXE3300 using Dipole 90x

Pattern Transfer

Step	CD	3σ (wfr)	LWR	3σ (wfr)
Litho	20.6 nm	1.6 nm	3.7 nm	0.3 nm
Etch	16.4 nm	1.2 nm	3.6 nm	0.3 nm
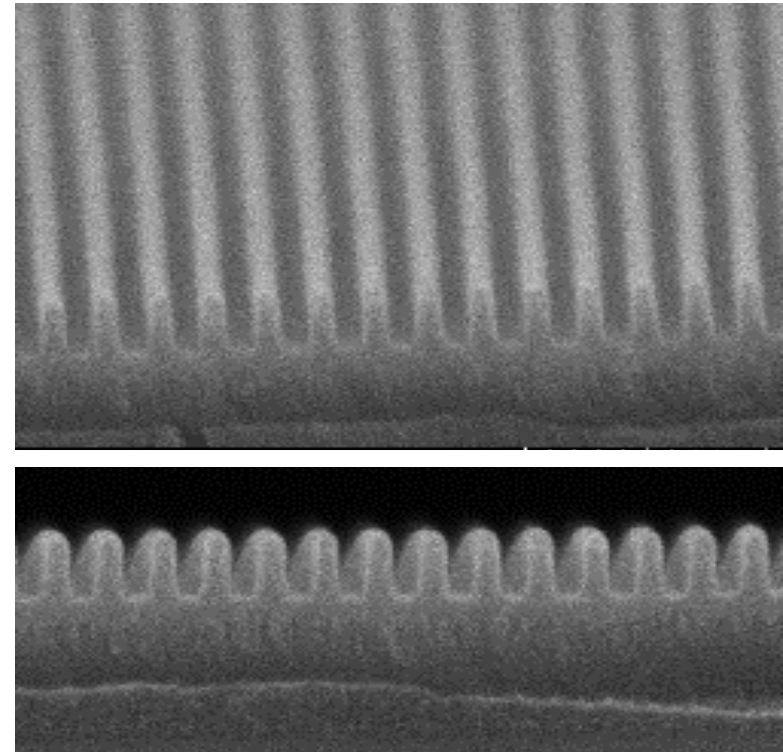
- First pass un-optimized patterning & etch
- CDU & LWR of Litho Pattern ⇒ Etch Pattern match with good sidewall profiles
- Indicates excellent resist etch selectivity
- Now moving to 2D block mask patterns

Summary

Focus on Demonstrating the N7 Block Mask Patterning Module

Patterning Performance

Fab Integration (Lab2Fab)
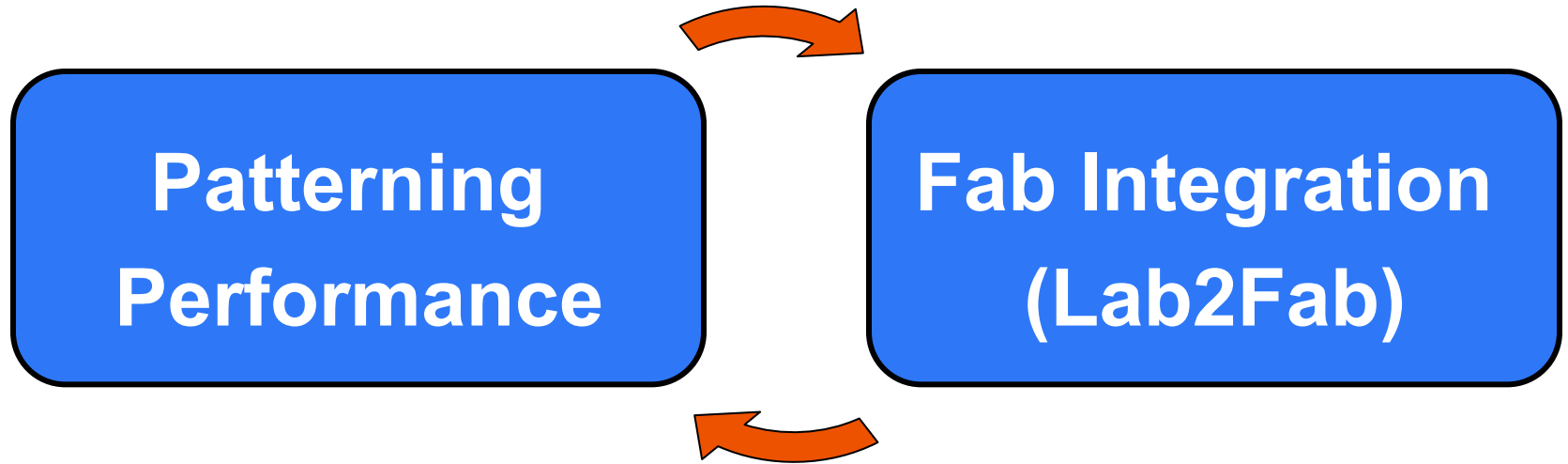
2D patterning with path to <20 mJ/cm^2

Targeting readiness on all parameters for N7 insertion

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Thank You!

- ASML

- TEL

- SCREEN

- Entegris

- LBNL CXRO

- PSI

- IMEC

  ... and to all of our partners