Preserving Printed Wafer CD Stability in High-Frequency EUVL Mask Cleaning

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Outline

- Background
- Initial POR Performance
- POR Segmentation
- Advanced POR Performance
- Summary & Path Forward

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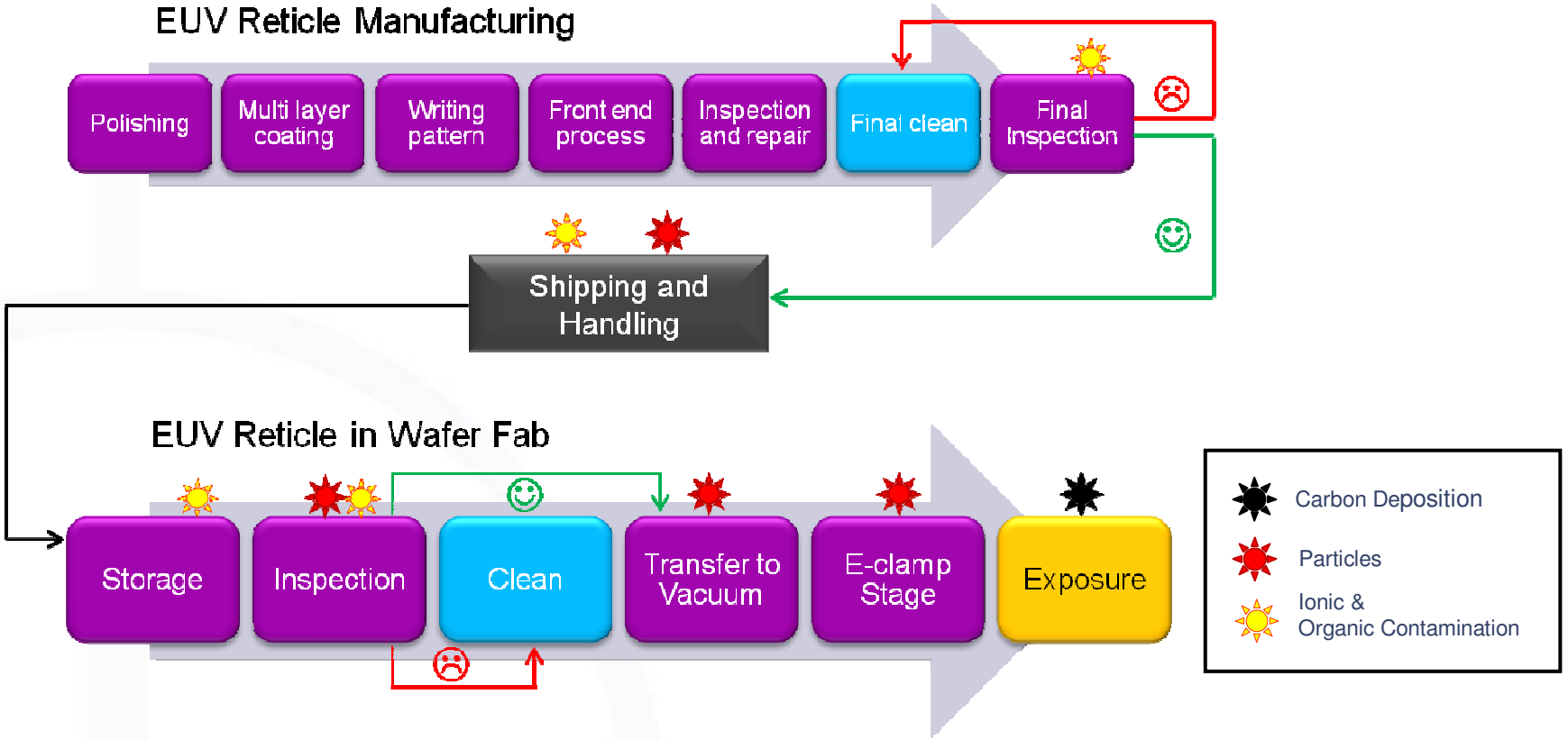
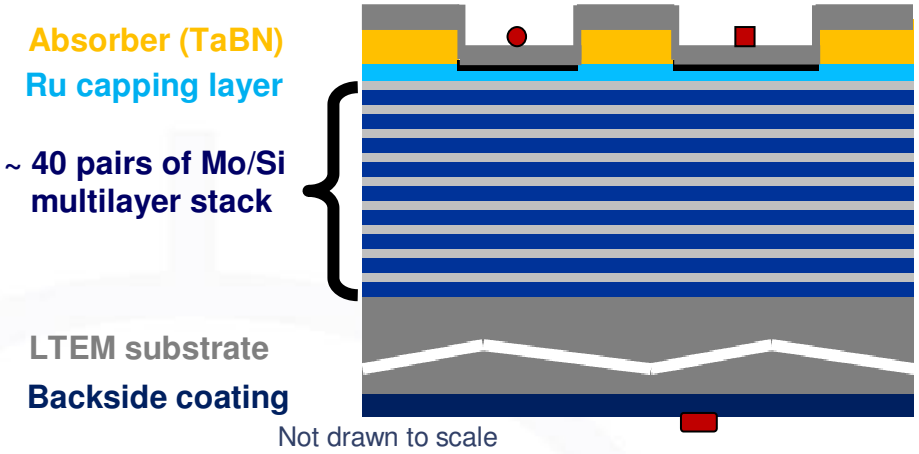
EUVL Reticle Contamination Risks



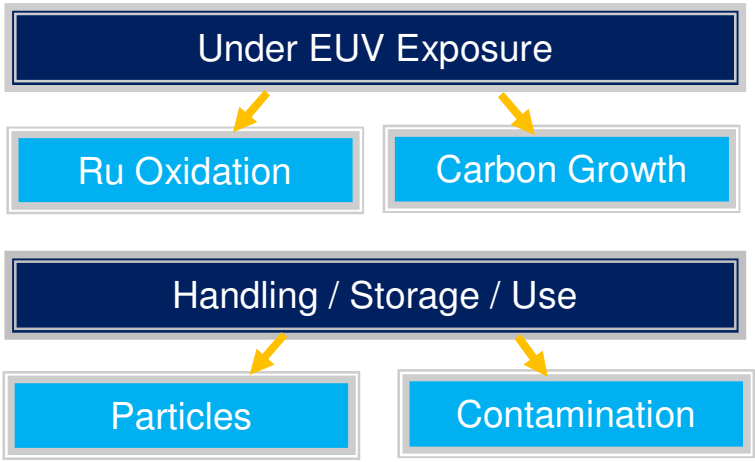
EUVL mask cleaning frequency predicted to be higher than in 193i Lithography

Source: ASML, HamaTech-APE

EUVL Mask Cleaning Requirements



Not drawn to scale



	EUV Reflectivity	CD shift (non-uniformity)	Litho Fidelity/Stability	Mask Life Time
Ru Oxidation	↓	↓	↓	↓
C deposition	↓	↓	↓	↓
Particles		↓	↓	

Goal → **Restore** → **Remove** → **Preserve**

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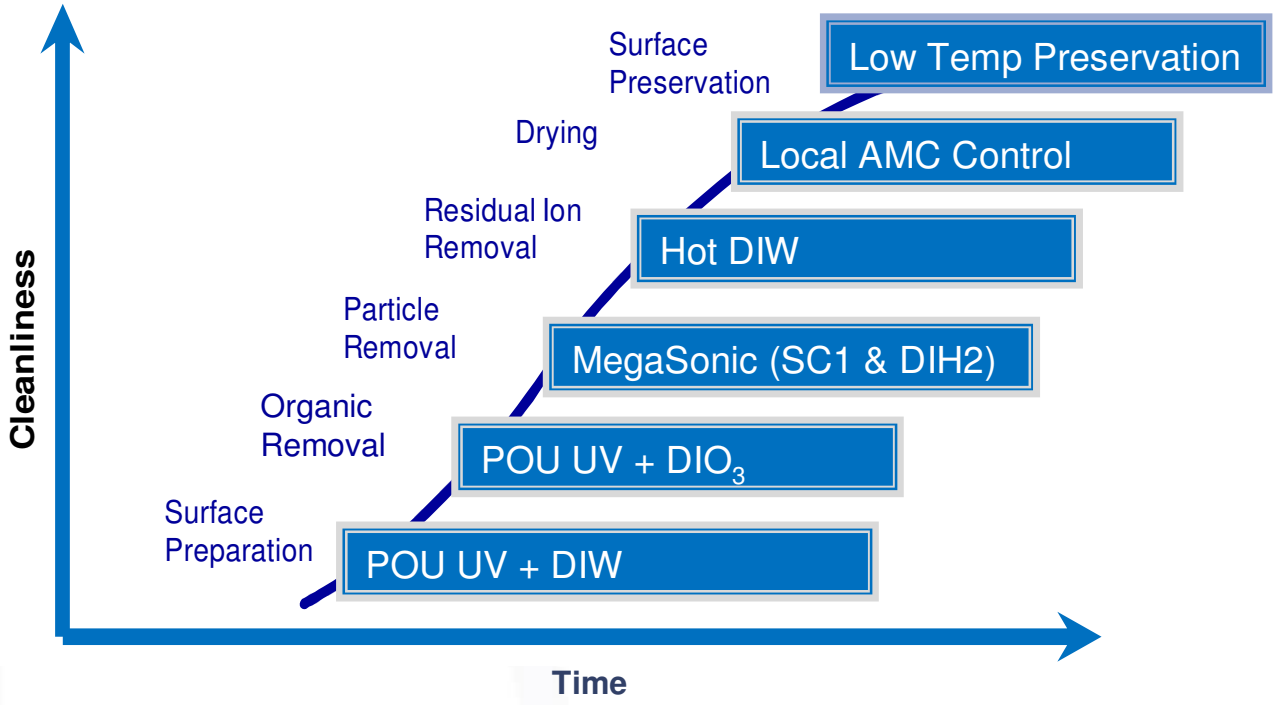
Initial POR Sequence



Initial POR Performance Results

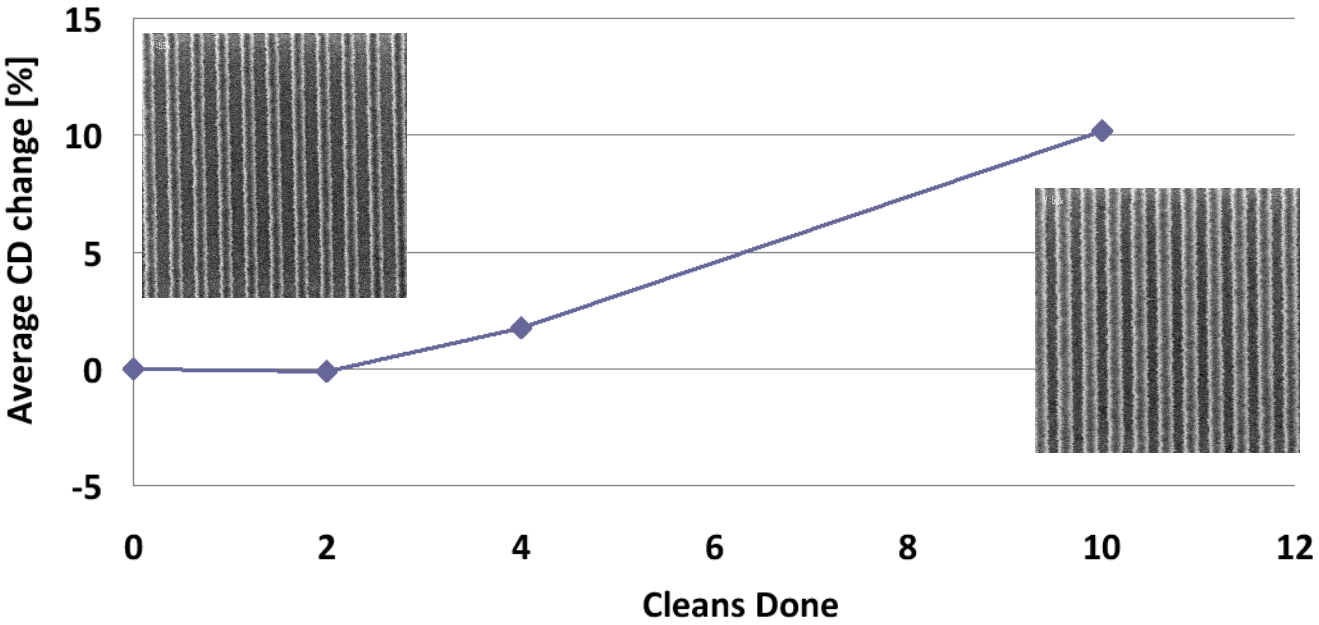
Blanks:

☑ **Complete removal** of EUV induced **Carbon**	1 x POR
☑ **No degradation** in EUV **reflectivity**	30 x POR
☑ **High stability** in Multilayer structure (based on XPS)	10 x POR
☑ **No increase** in **surface roughness** of Ru	10 x POR
☑ **< 0.03nm decrease** of **Ru** thickness per clean	30 x POR
☑ **> 99% PRE** for SiN @ 60nm	

Pattern Masks:

☑ **Complete removal** of printable natural defects (handling, storage)	
☑ **No feature damage**	10 x POR
☑ **Minimal CD shift** on **mask level**	30 x POR
❑ **Unacceptable CD shift on wafer level**	**>5 x POR**

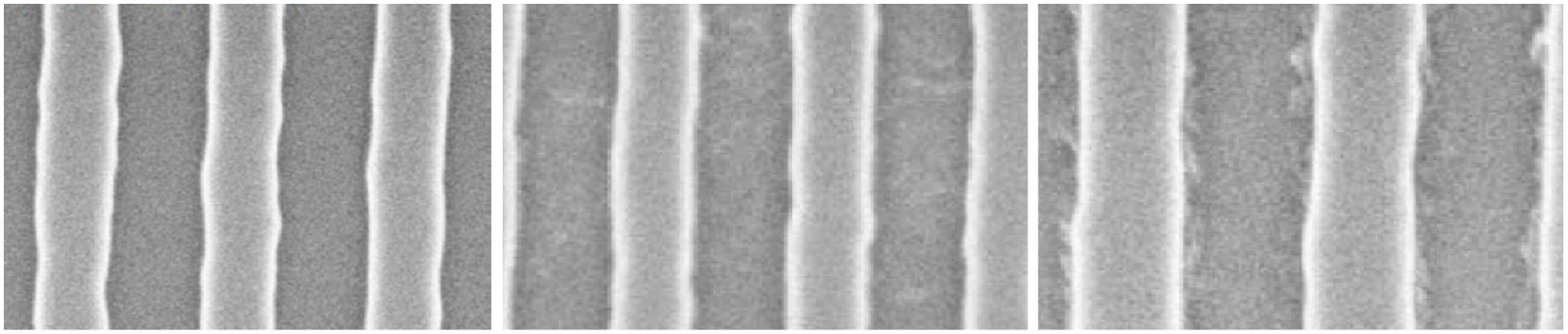
ADT Wafer Print CD-Shift (initial POR)



- Small CD shift observed after 4x clean.
- Severe CD shift observed after 10x clean
- Same recipe did not show any deterioration of ML Blank

Mask Level Analysis

SEM Images for various stages of ML damage



No apparent damage

Some ML damage (increased surface roughness)

Severe ML damage (ML peeling)

- ML damage is typically progressing from increased surface roughness (“cracking”) to ML peeling
- ML damage can be highly non-uniform across the mask, with all three stages of damage present on the same mask

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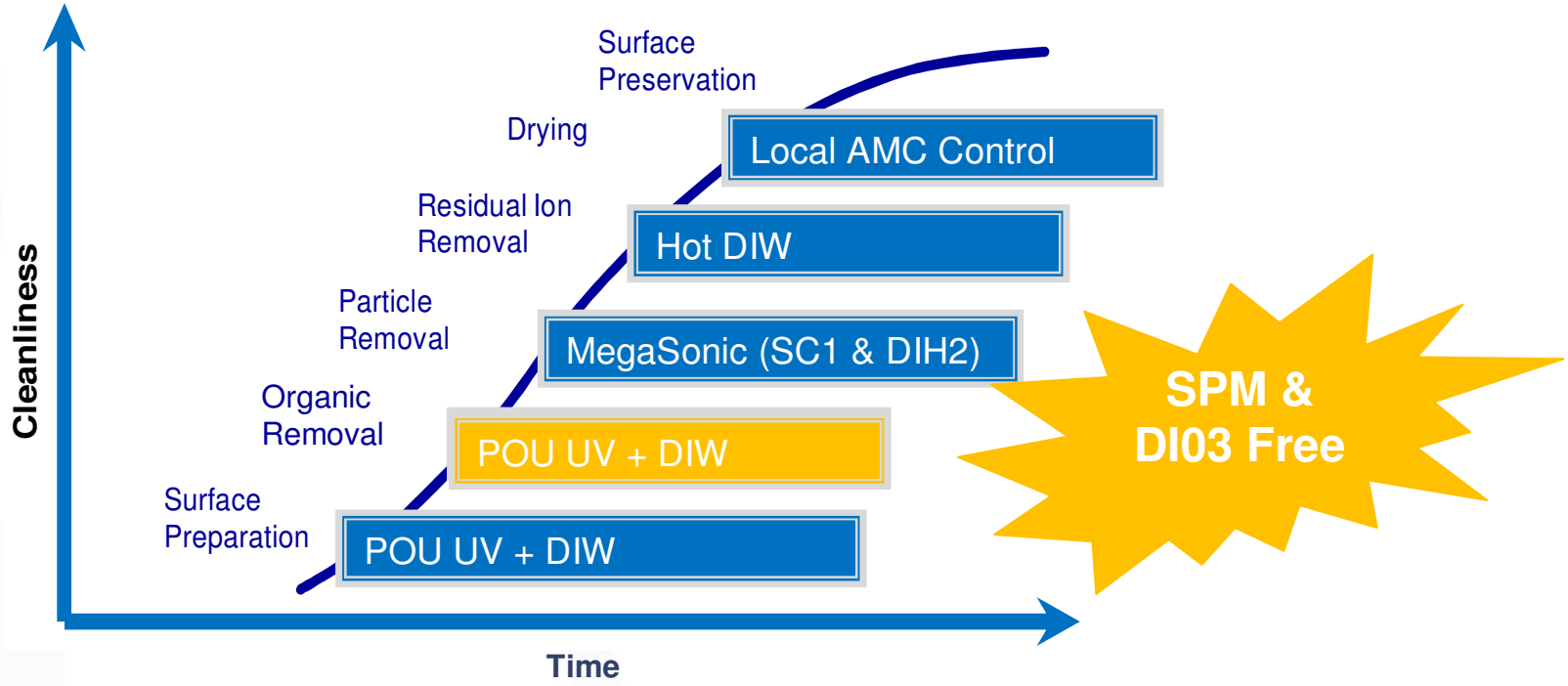
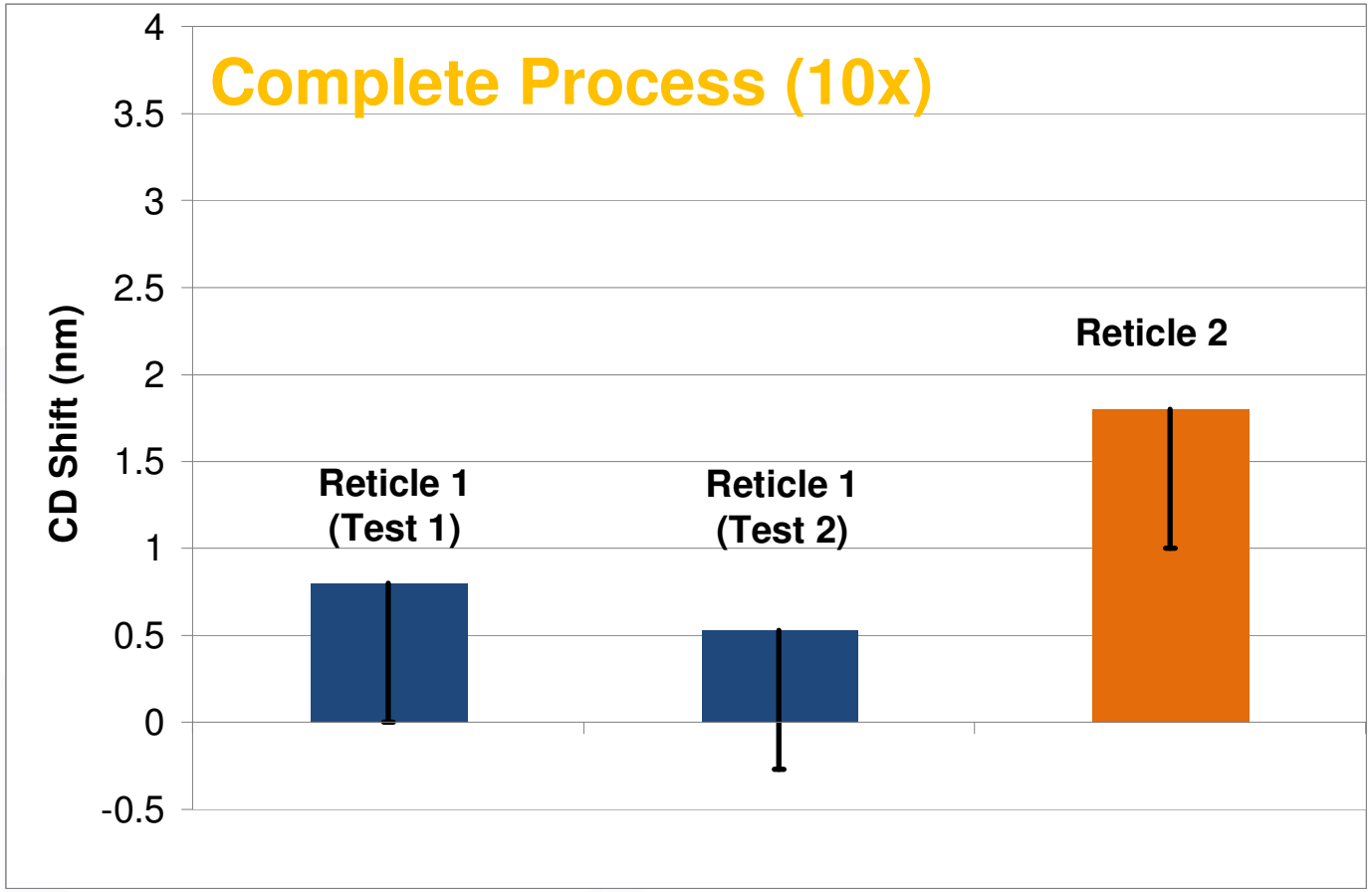
Modified POR Sequence



+ Cleaning further “softened” by removing DIO3 also from PoU UV process step.
+ Cleaning now 100% SPM- and DIO3- free.

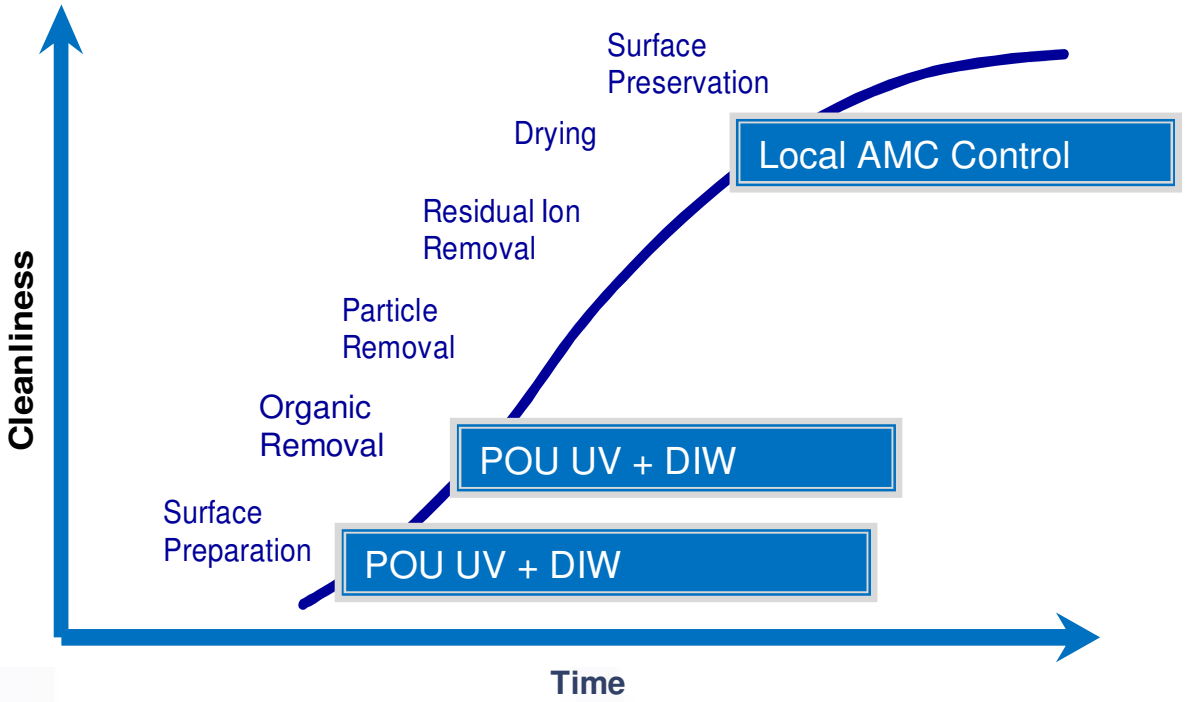
POR Segmentation



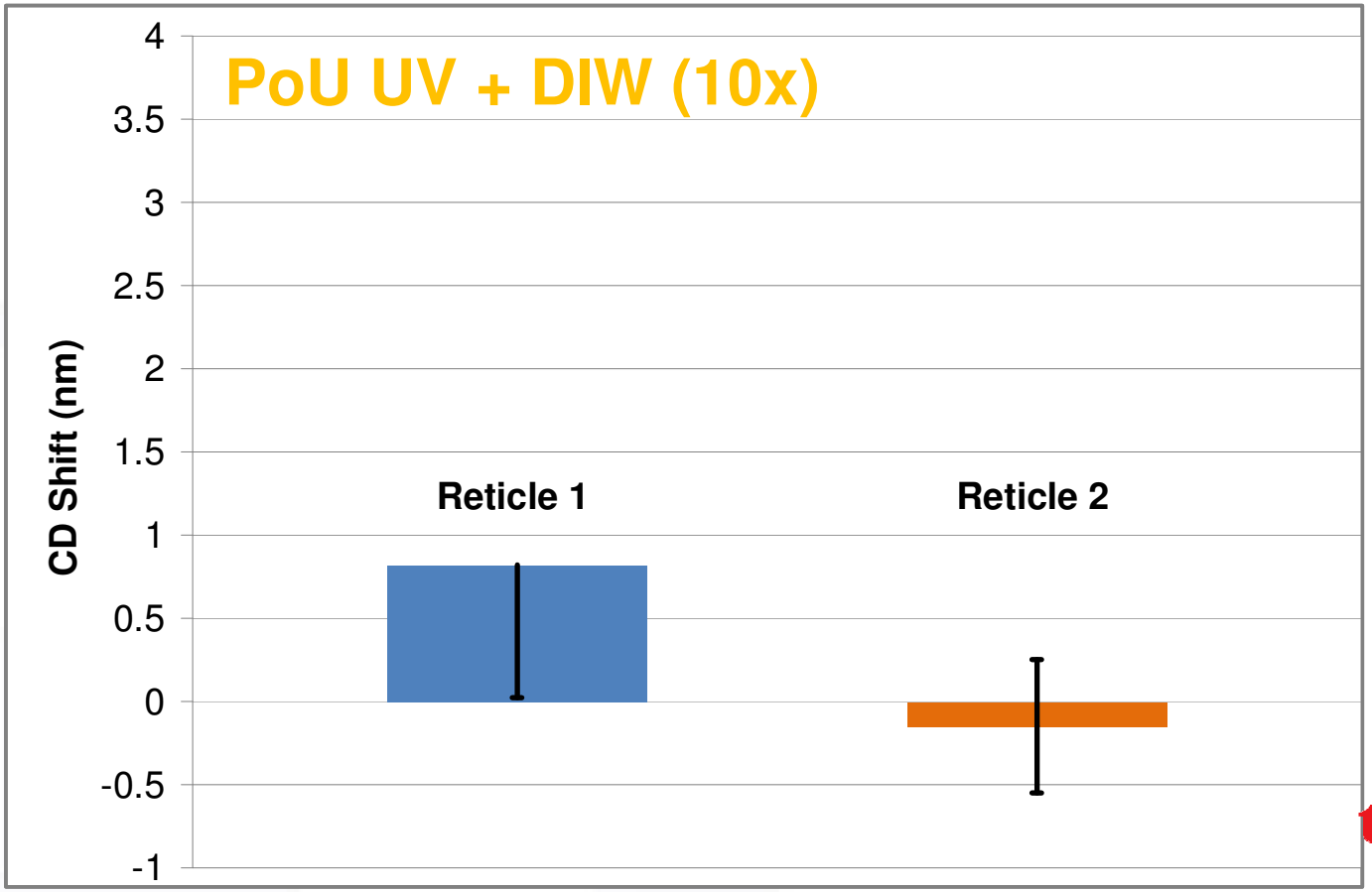
+ **Reticle 1**: Wafer level CD change **within daily monitor print variation.**
+ **Reticle 2**: Wafer level CD change **~ 3x smaller** than initial POR, but still **unacceptable**

POR Segmentation

PoU UV + DIW (10x)

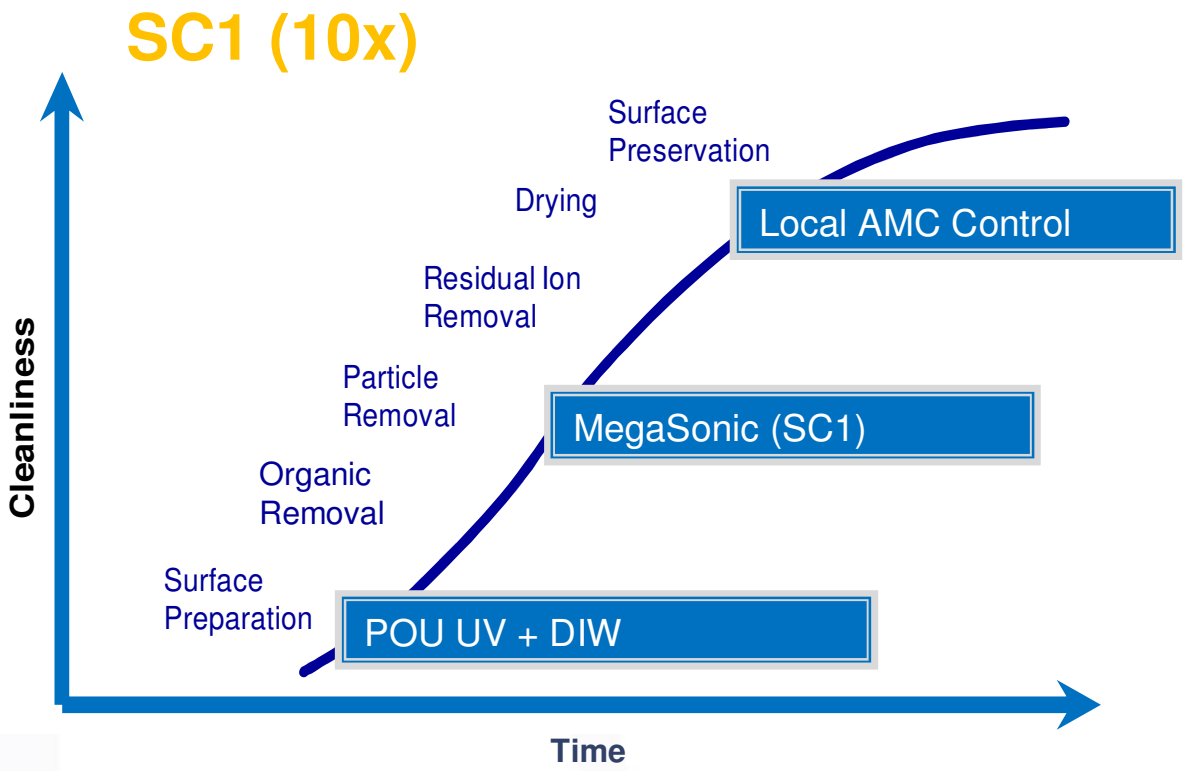


POR Segmentation

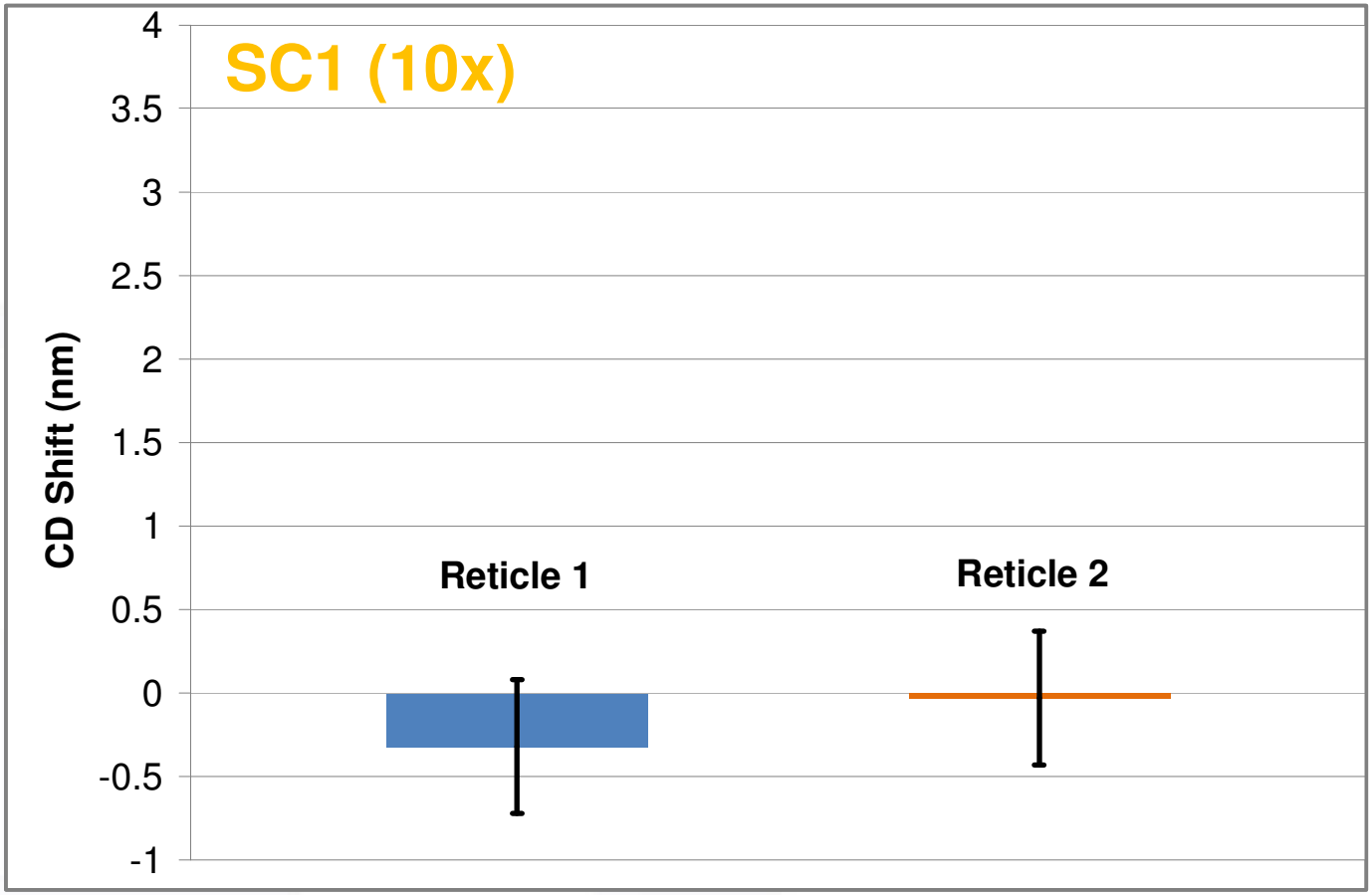


+ **Reticle 1 & 2:** Wafer level CD change **within daily monitor print variation**

POR Segmentation

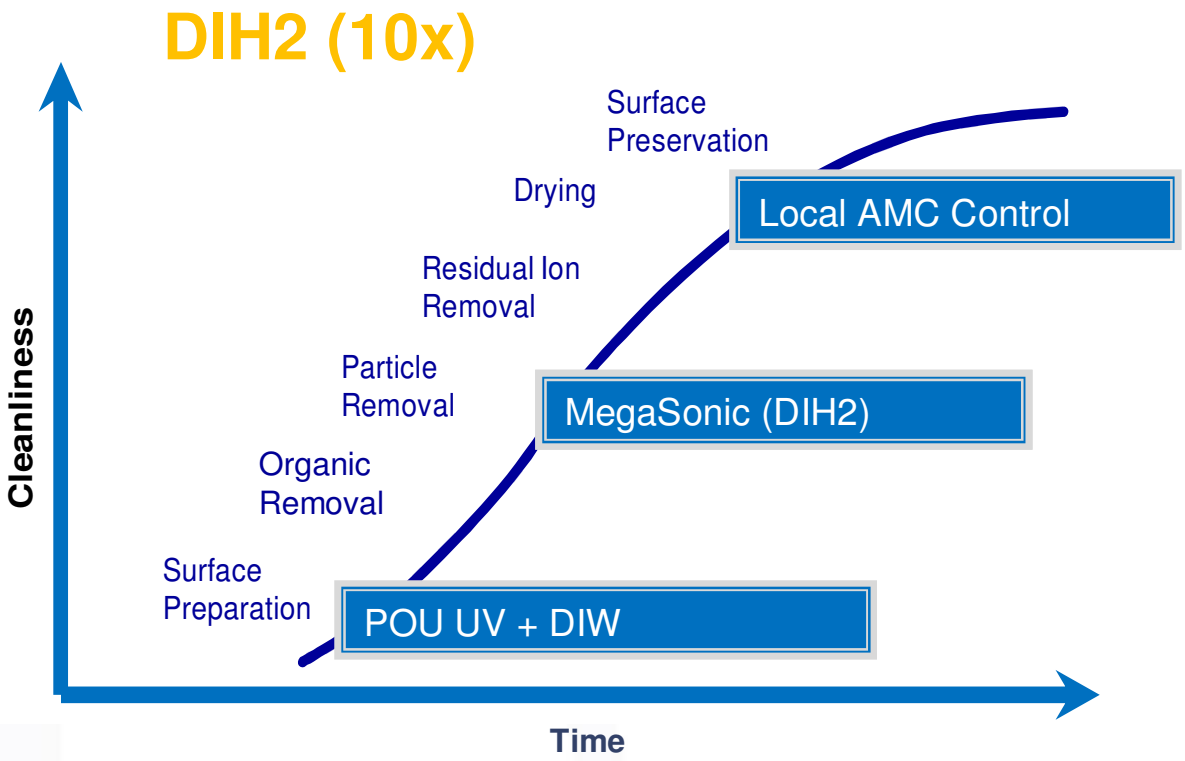


POR Segmentation

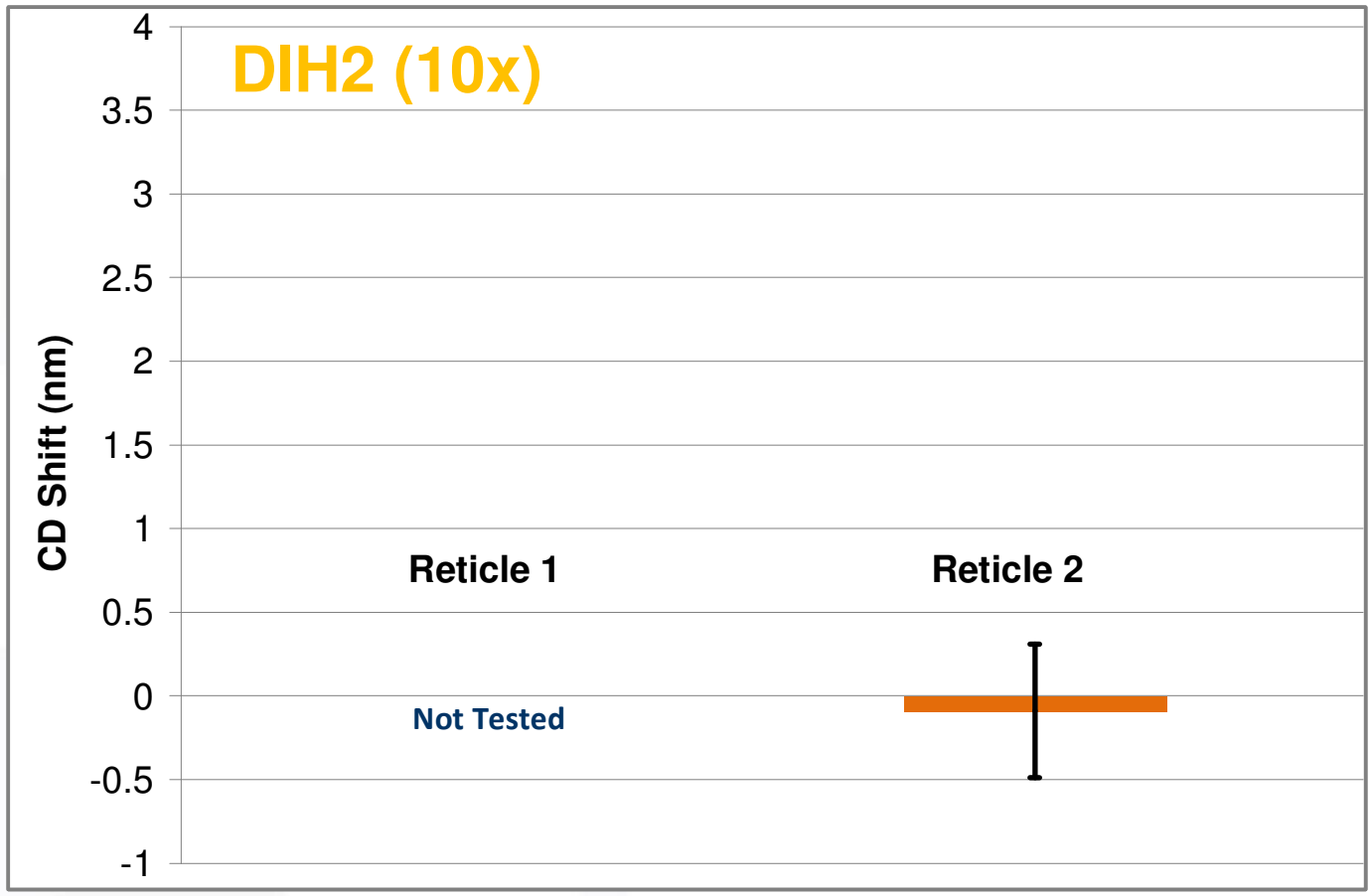


+ **Reticle 1 & 2:** Wafer level CD change **within daily monitor print variation**

POR Segmentation

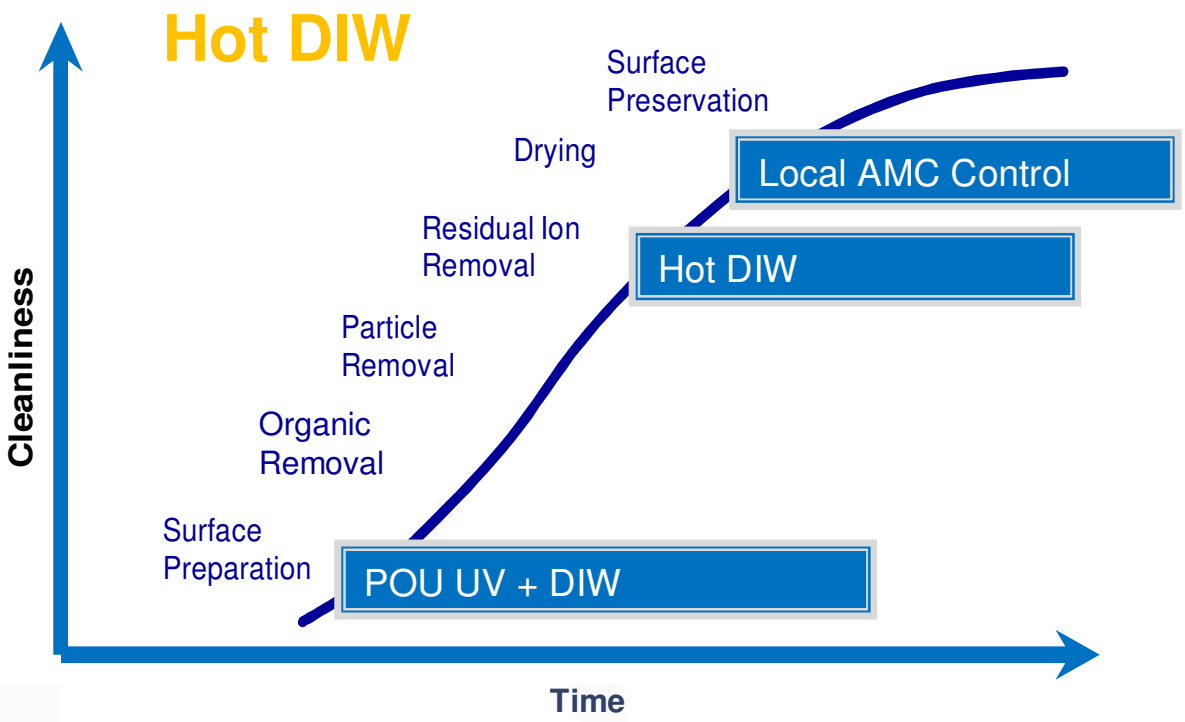


POR Segmentation

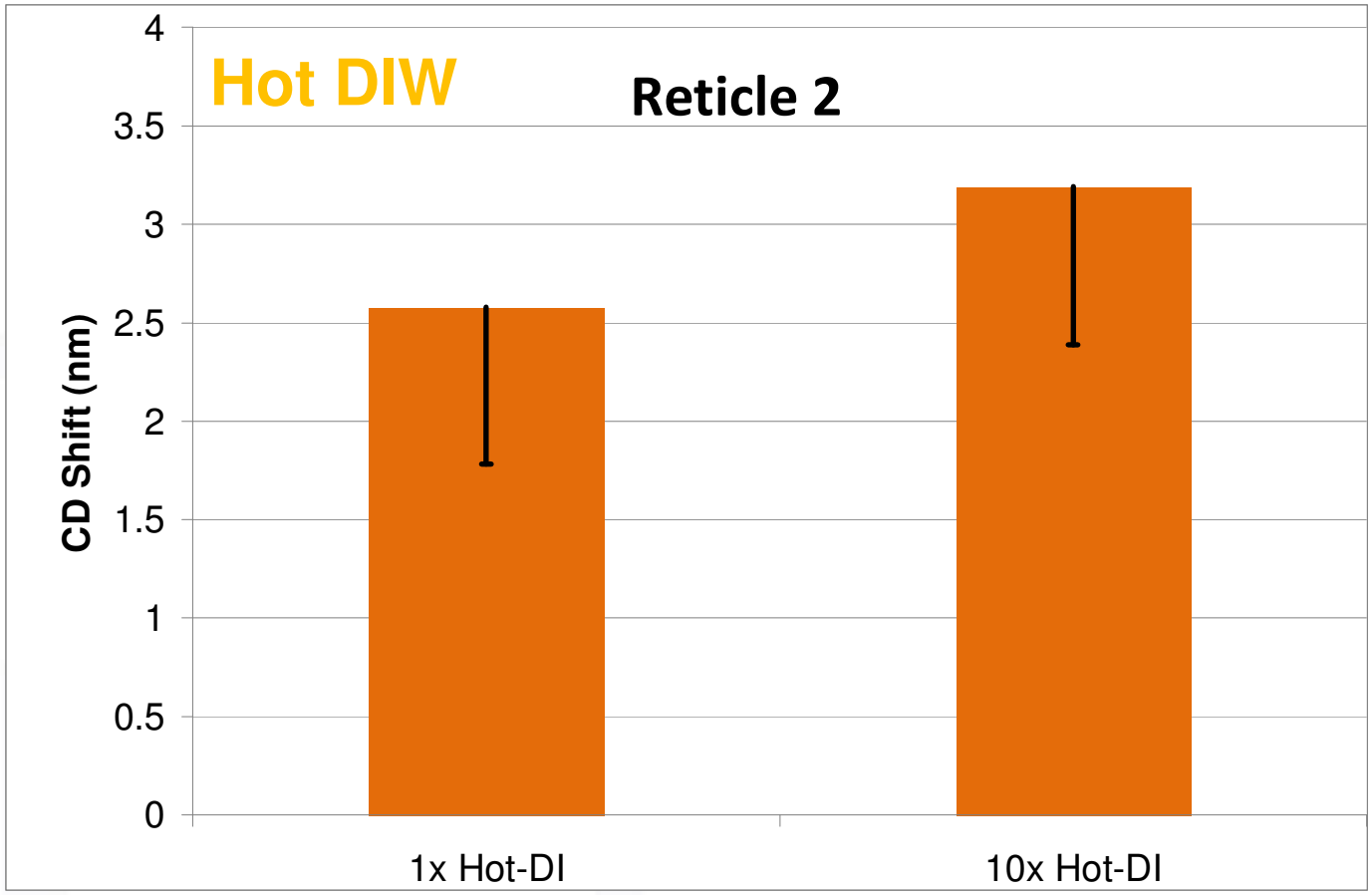


+ **Reticle 2:** Wafer level CD change **within daily monitor print variation**

POR Segmentation



POR Segmentation



+ Severe CD shift observed after 1x hot water rinse.
+ Additional CD shift after 10x clean, but slowing down

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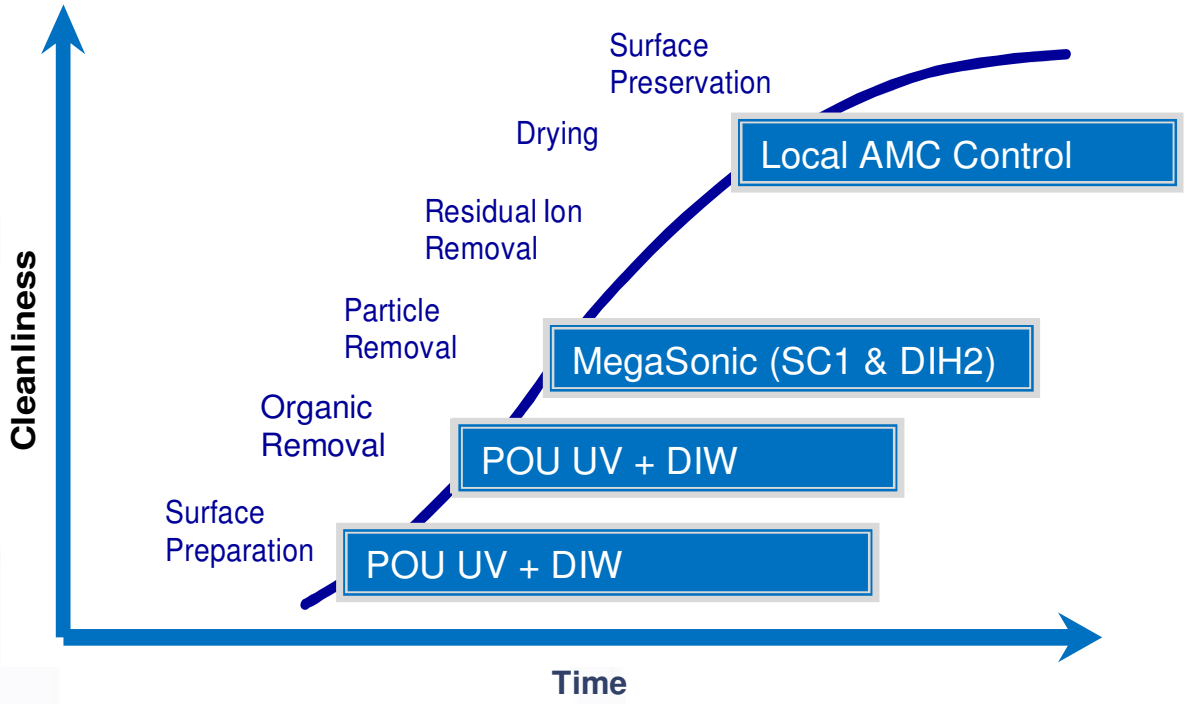
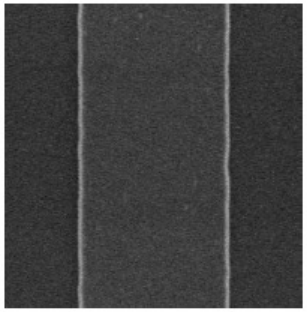
Advanced POR Sequence



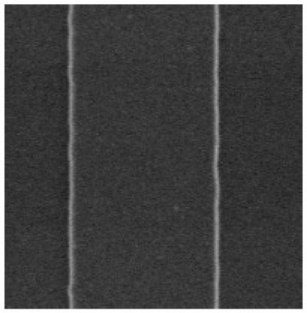
- Hot water rinse removed from process.
- Cleaning still 100% SPM and DIO3 free.

Mask CD after 32x Advanced POR

Marathon Clean with DNP Evaluation



Before cleaning



After cleaning

- Based on recent ADT reticle, not used because replaced by NXE3100 version
- NO ADT printing results
- Mask metrology comparison before vs. after

Mask abs. CD	CD change	3sig before cleans	3sig after cleans
600nm	-3.6nm	3.0nm	3.4nm
360nm	-3.1nm	1.9nm	2.4nm
248nm	-2.8nm	3.4nm	3.7nm

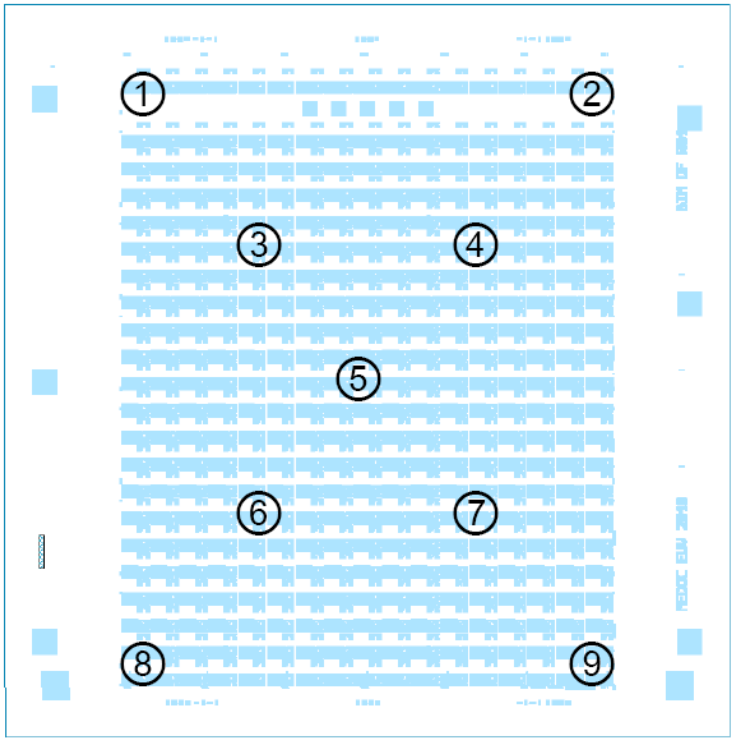
DNP

+ Mask CD shift at mask level is **reasonably controlled** within 1Å per clean
+ Mask CD Uniformity is **nearly unchanged** after 32x clean

Surface Roughness after 32x Advanced POR

Marathon Clean with DNP Evaluation

AFM roughness measurements



RMS (nm)	Reference Mask ML 0.15…0.2nm	ABS 0.45…0.6nm
position	ML	ABS
1	0.14	0.556
2	0.229	0.526
3	0.199	0.587
4	0.207	0.586
5	0.211	0.467
6	0.221	0.553
7	0.203	0.612
8	0.200	0.444
8'	0.205	-
9	0.153	0.411

DNP

+ Roughness of ML and Absorber **comparable** to reference mask after 32x clean.

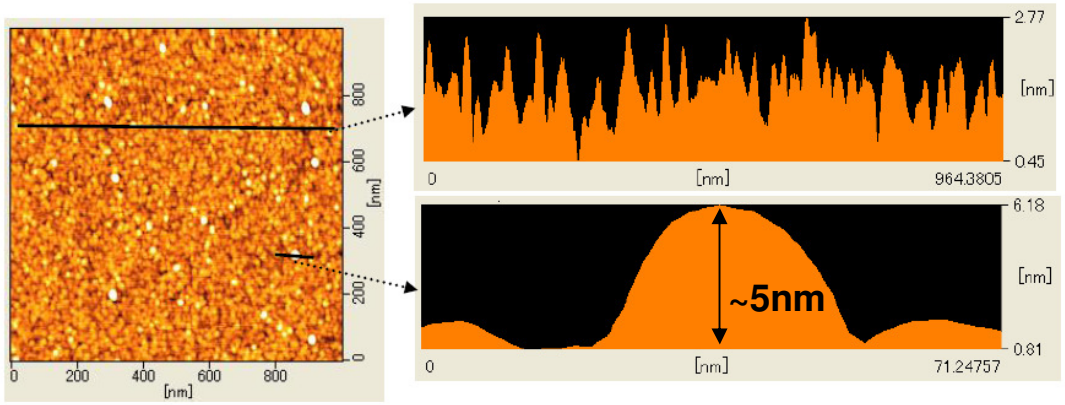
Surface Roughness after 32x Advanced POR

Marathon Clean with DNP Evaluation

Mask center Absorber

RMS 0.46nm

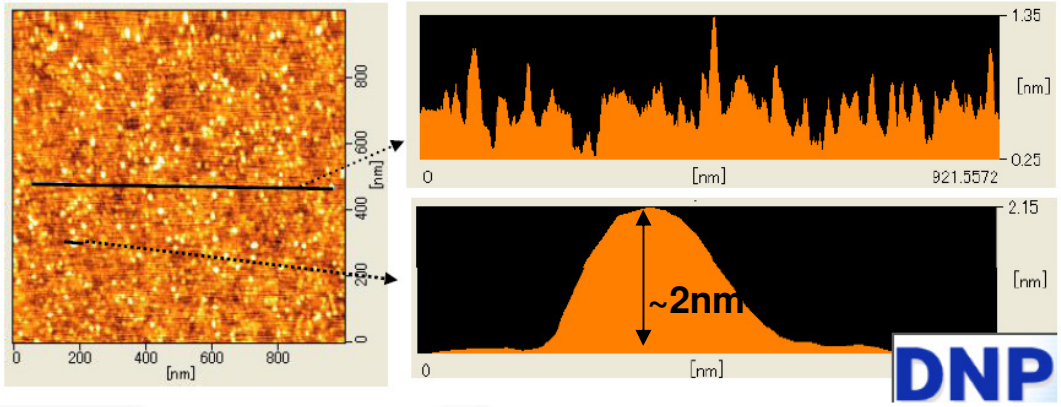
Reference Mask RMS 0.60nm



Mask center ML

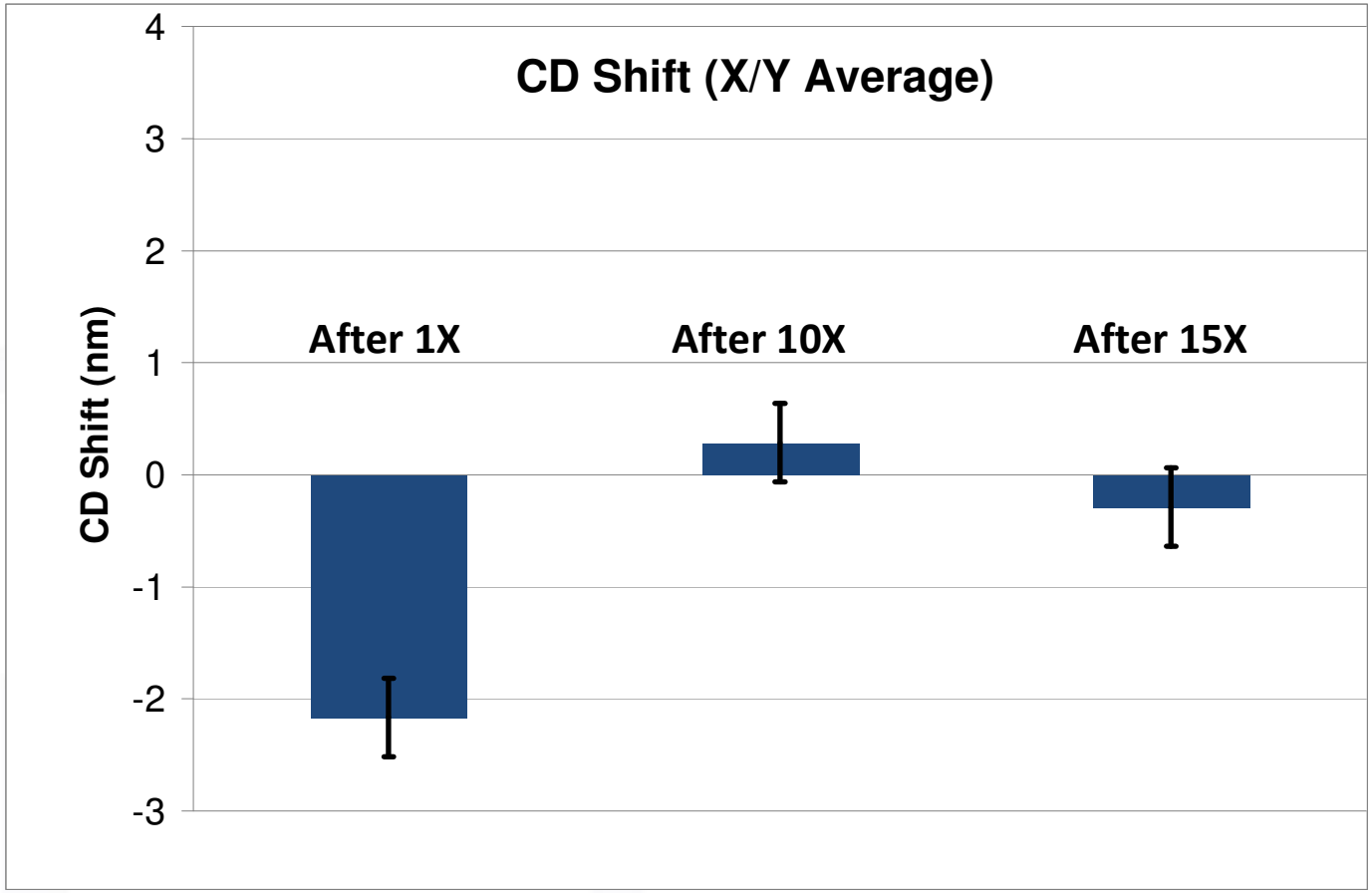
RMS 0.20nm

Reference Mask RMS 0.18nm



+ Some Nanometer Scale Bumps observed after 32x cleaning

Advanced POR Wafer Level Performance



+ Wafer **CD mean decreases** after first clean → suspected **carbon removal**
+ **No significant CD shift** at wafer level throughout next 14 cleans

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Summary

- Wafer CD shift of **original POR** mainly a result of **ML damage** (cracking → peeling)
- Process segmentation revealed:
  - No shift in printed CD using **DIO3 free** PoU UV process
  - No shift in printed CD using **Megasonic** clean (SC1 and DIH2)
  - Severe CD shift through **hot DIW** rinse
- Advanced SPM- and DIO3- free POR delivers:
  - **Mask level** CD degradation **< 1A per clean** over 32 cleans
  - **Wafer level** CD stable **at least up to 15x clean**
- Wafer **CD performance** of masks contaminated through extensive use, storage and handling is **fully restored** using the Advanced POR (single clean)

Path Forward

- Extend mask level CD stability testing beyond 32x clean
- Investigate Nanometer Scale Bumps
- Extend wafer level CD stability testing beyond 15x clean
- Further investigate effect of Hot DIW Rinse on ML integrity
- Verify PRE performance of Advanced POR for front and backside clean
- Study effect of reticle manufacturing footprint on ML damage
  (e.g. interaction between patterning and resistance of Ru Capping and/or Absorber to cleaning)

Acknowledgement

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