18X surface cleaning impact on process performance of an EUV mask

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Mask cleaning as a viable solution to preserving lifetimes for EUV high volume manufacturing

Contamination is inevitable

EUV masks are expensive

Mask cleaning is necessary

How many times can a mask be cleaned before significant impact on lithographic performance is observed?

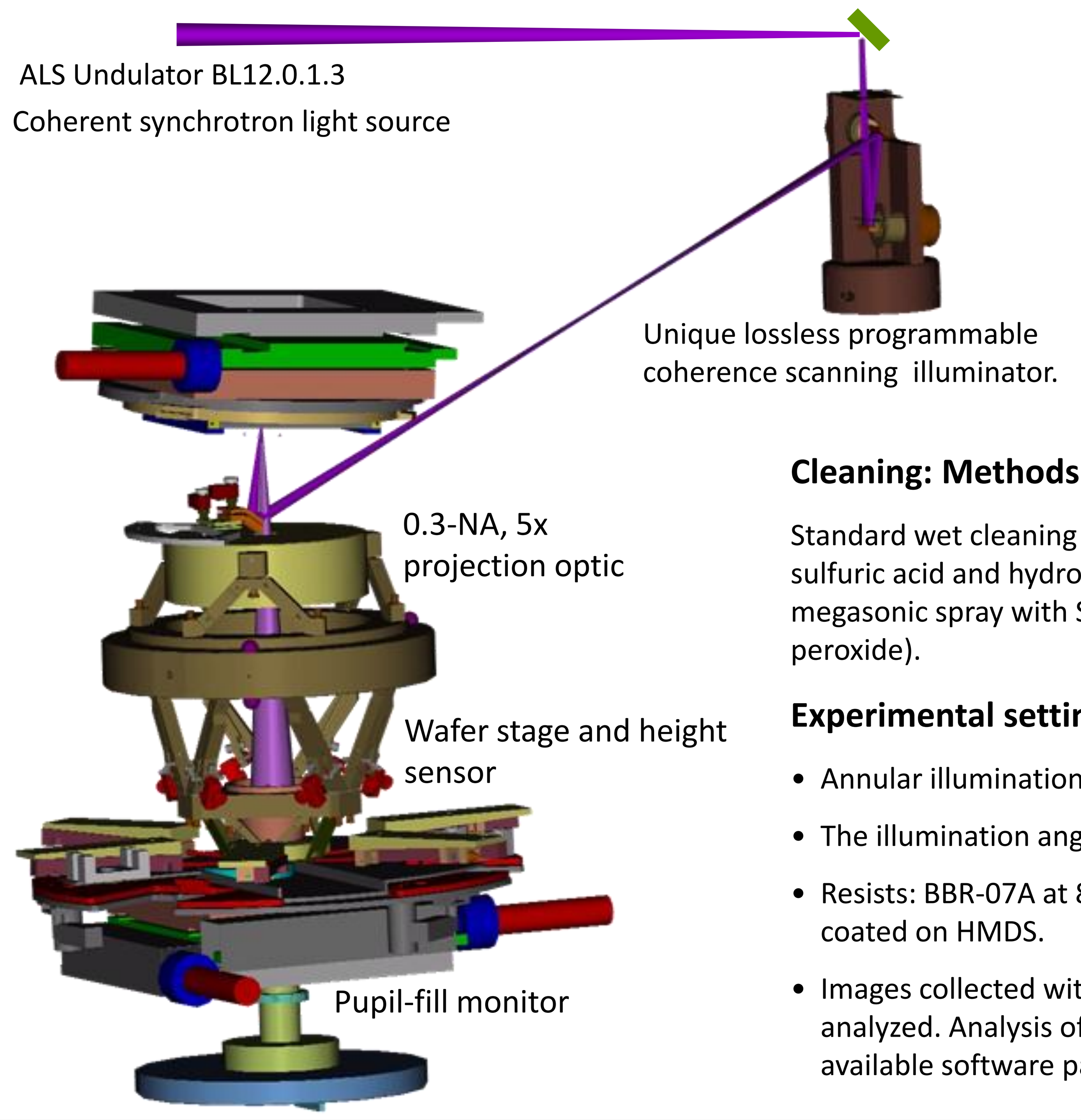
1. Cleaning processes may damage the delicate mask multi-layers or may increase the mask absorber pattern side-wall and surface roughness.
2. Cleaning cycles may increase the multilayer top surface roughness, contributing to speckle.

Either will contribute to reduced patterning fidelity as a result of throughput loss, increased scattering/speckle effects, and LER.

This paper presents detailed exposure analysis and process comparison to determine the impact of multiple mask cleans cycles on patterning performance.

Patterning studies with the SEMATECH-Berkeley 0.3 NA micro-field exposure tool

EUV nanolithography system at ALS BL 12.0.1.3



Zeiss MET optic

- Mag. = 5x, NA = 0.3
- Field size = 0.2x0.6 mm

Programmable coherence illuminator for low k_1

Sub-nm resolution focus control

Rapid mask and wafer exchange

Pupil-fill monitor

Cleaning: Methods

Standard wet cleaning chemistries; three main steps, 1) organic removal by a mixture of sulfuric acid and hydrogen peroxide, 2) DI water rinse, and 3) final particle clean by megasonic spray with SC1 (DI water with diluted ammonium hydroxide and hydrogen peroxide).

Experimental settings:

- Annular illumination with inner and outer sigma of 0.35 and 0.55, respectively.
- The illumination angle of incidence is 4 degrees parallel to the mask patterns.
- Resists: BBR-07A at 80nm film thickness and BBR-08B with 60nm film. Both resists were coated on HMDS.
- Images collected with Hitachi S4800 FE-SEM. For this study, over 2000 images were analyzed. Analysis of the recorded images were completed offline with the commercially available software package SUMMIT.

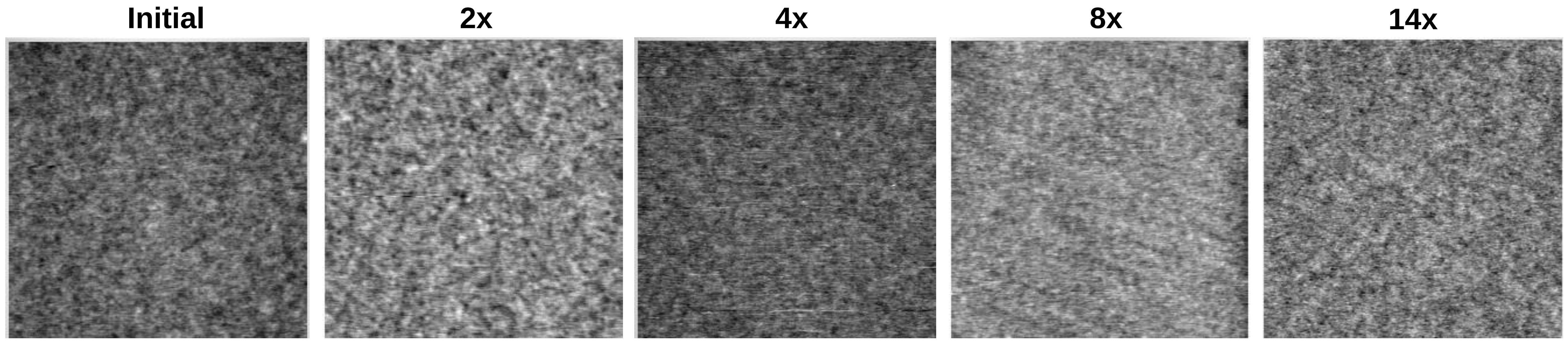
Long term systematic studies for the impact of mask cleaning on patternability

Process performance of two different mask s were monitored throughout the year for isolating mask cleaning related effects

1. New mask fabricated specifically for monitoring cleaning effects, without prior illumination related contamination. The patterning performance was monitored after every two cleans. The same field is used each time the mask is patterned after cleans.
2. Reference mask for control and comparison. A field on this mask was imaged each time the cleaned mask was monitored for process at the Berkeley MET.
3. The key metrics for this study are the comparison of process windows and related Exposure latitude of the 40nm and 36nm half=pitch patterns, critical dimension (CD) matched line edge roughness, and changes in the cleaned mask top surface roughness as measured by AFM.

Multilayer top roughness vs. the number of cleans

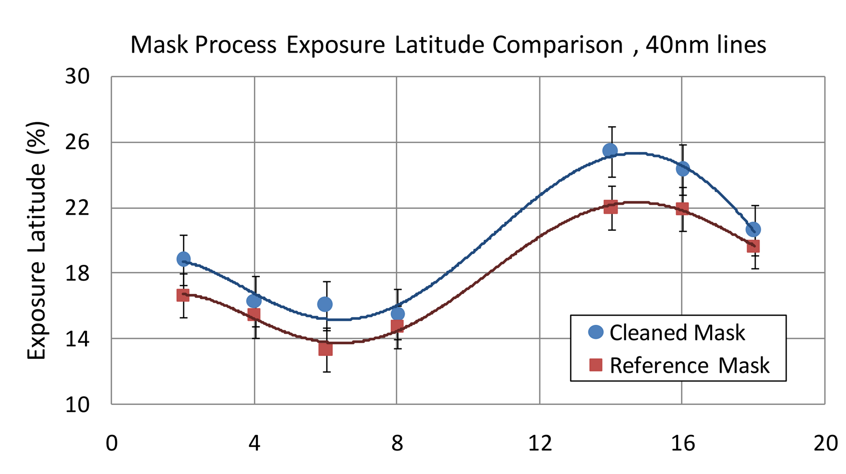
Initial	2x	4x	8x	14x

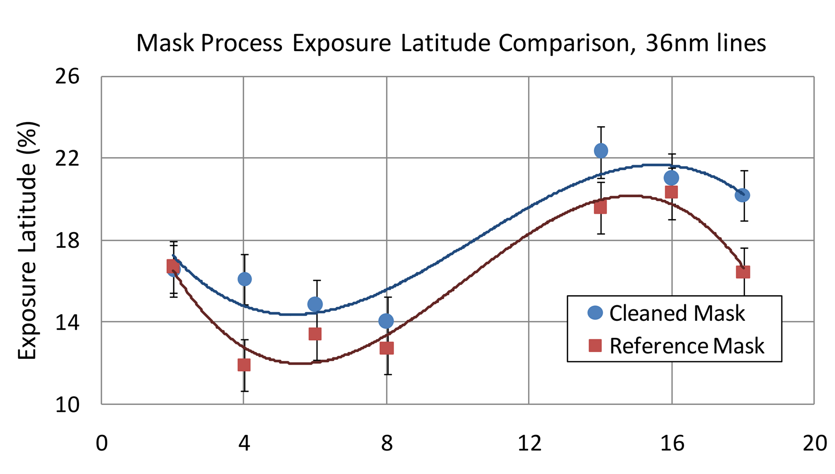


MSFR – 0.057nm	MSFR–0.056nm	MSFR–0.060nm	MSFR-0.056nm	MSFR-0.066nm

Mask blanks are qualified at the mid spatial frequency roughness (MSFR), in the 0.1-1.0nm range. The processed AFM data does not show changes in the rms roughness or the MSFR that is significant beyond the measurement error. 16x and 18x clean surface data is not available at this time.

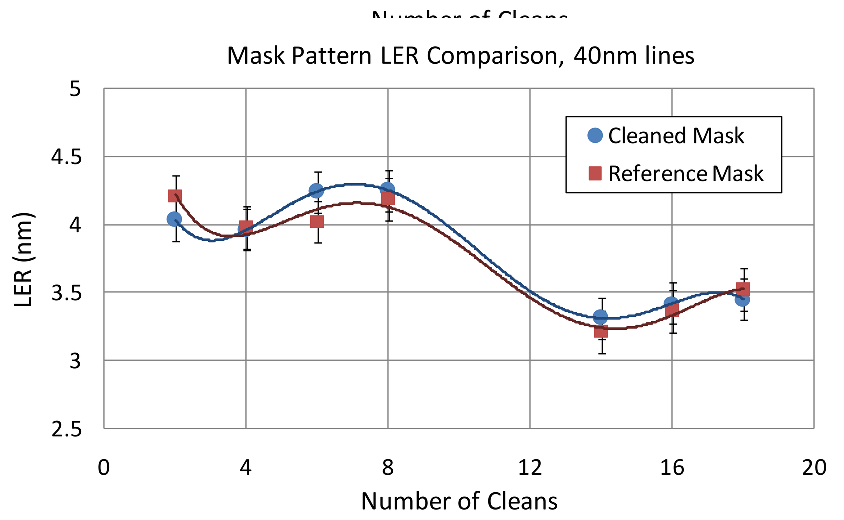
Process performance comparisons: the cleaned mask and the reference mask at 18x cleans

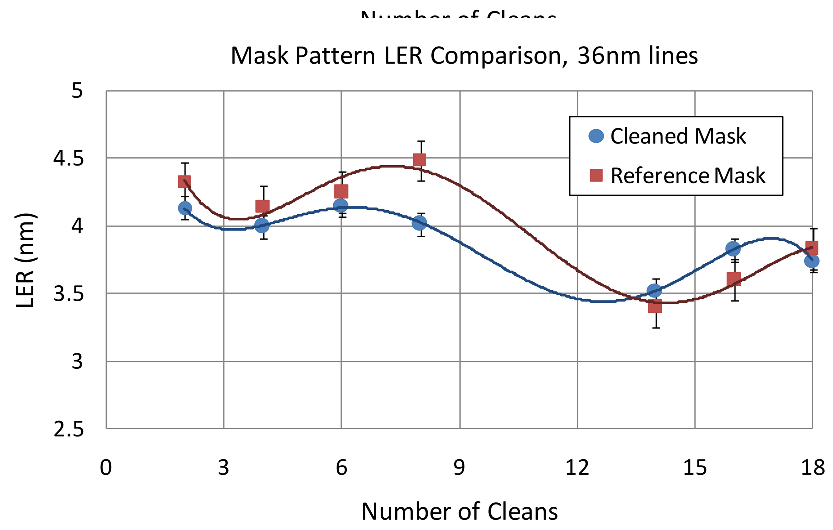




Process trends are identical for both masks barring any changes in Exposure tool and resist performance.

Cleaned mask process performance have been slightly better than the reference mask imaging latitude from the onset of these studies.

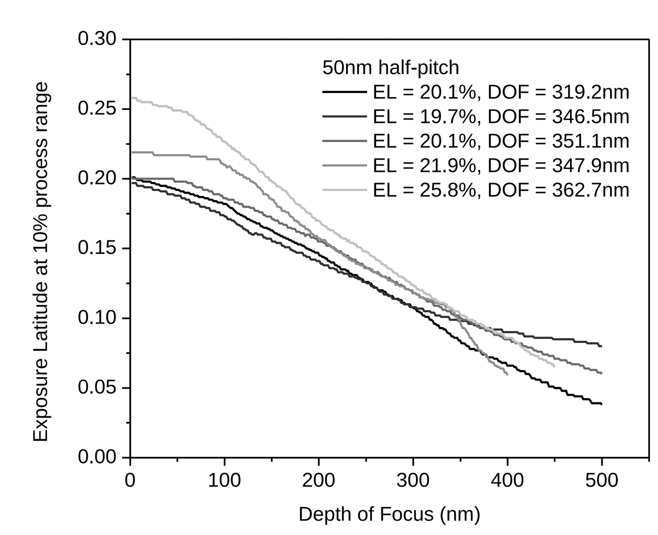




CD matched LER from the best focus and dose area of the MET field exposure matrix. Each data point is an average 216 line edges from 12 SEM images, at a magnification of 120KX, with 9 lines in each image.

Process Stability: Isolating MET process error

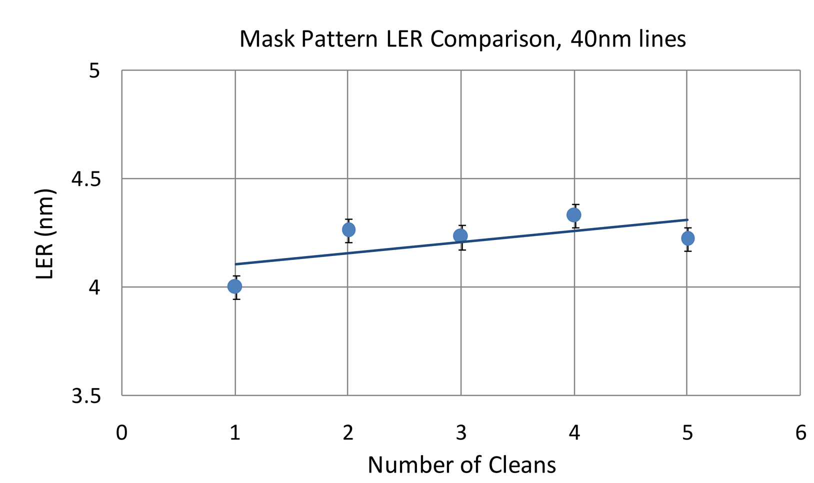
Repeat measurements over an 8-hour beam shift on BBR08A, 5 process windows. Film thickness= 60nm on HMDS @ 125^{0}C, PAB = 110/90, PEB = 100/90, Dev = TMAH, 30 Sec



Exposure Latitude Comparison of five process windows of the same resist

Rectangle fit
Absolute EL change = **5.7%**
Absolute DOF change = **43.5nm**

50nm half-pitch



Best LER (best dose and focus area) = **4.00nm** for average CD at **48.5nm** for dose at **13.6 mJ/cm²**

LER average of 360 edges, from 20 best CD matched images for each process window.

LER range: **4.0 – 4.33 nm**, giving a process uncertainty in LER at approximately **0.33nm for these measurements**

Summary

- Observed patterning differences between the two masks are found to be within the expected process error of 5 -10% .
- AFM data for mask blank qualification does not show changes in the computed surface roughness.

Lithographic performance is unchanged after 18 cleaning cycles.

Acknowledgments

Ted Liang from Intel for the initiation of the studies. Operations support is provided by Paul Denham, Brian Hoef, Gideon Jones, and Nathan Smith with the exposure tool. We acknowledge SEMATECH for the financial support of the SEMATECH Berkeley MET and the programmatic support from SEMATECH members Warren Montgomery, Bryan Rice, and Stefan Wurm. This work was carried out at Lawrence Berkeley National Laboratory's Advanced Light Source and at Intel corporation, Santa Clara.

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2010 International Symposium on Extreme Ultraviolet Lithography, October 17-20, Kobe, Japan