Microbridge reduction in negative tone imaging at photoresist point-of-use filtration

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ABSTRACT

It is well known that point-of-use (POU) filtration is an effective means of reducing microbridging defects in lithographic processes involving photoresists.. To date, most of the optimization studies have been targeted toward understanding the microbridging defects in positive tone imaging (PTI) process. Considering that negative tone imaging (NTI) process has recently been introduced in advanced technology nodes, we focused our POU filtration studies on understanding the factors that modulate microbridging in NTI and PTI processes. Our studies pointed out that Nylon 6,6 membrane is distinctly more effective in reducing microbridging defects in NTI resists, whereas HDPE membranes show significant improvement in PTI resists. These results were rationalized based on the polarity differences of microbridges in PTI and NTI processes.

Keywords: Microbridge, Bridge defect, negative tone imaging, photoresist, immersion lithography

1. INTRODUCTION

The process condition of the point-of-use filtration in photoresist dispensing is known to correlate with excursion of microbridge defects which may trigger critical problems such as disconnection and short circuit. As shown in Figure 1, many studies have been conducted in each lithography generation, to optimize process condition on filtration, and these have generated deep understanding of the requirements for optimization.

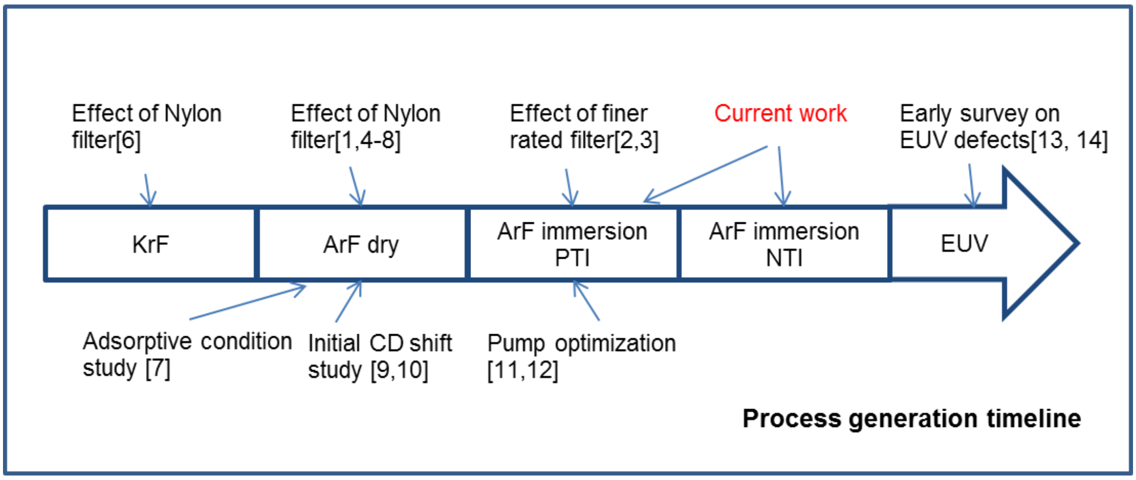

Figure 1 Existing microbridge study papers and current work positioning on lithography process generation timeline.

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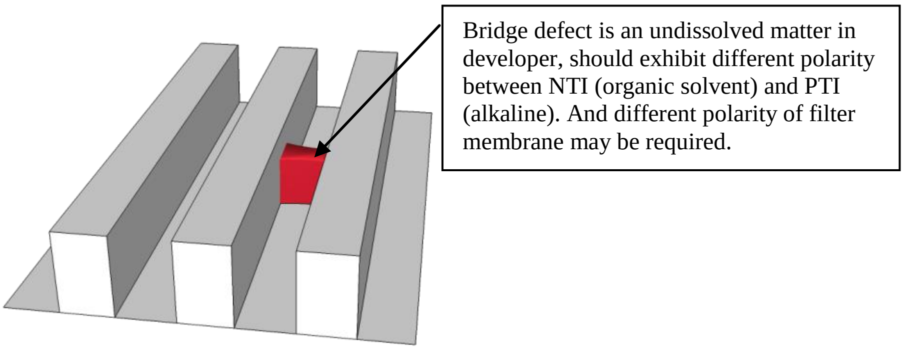
In regard to removal mechanism, for sieving effect, fine rated filter is effective especially in non-polar filtration membranes[1-3]. In contrast, polar nylon 6,6 membrane filtration is known to perform greater removal efficiency over sieving based ratings[1,4-8] and adsorption is concluded as the mechanism based on the membrane chemical structure and the observation of contact time dependence in artificial gel challenge tests[7]. Initial CD shift is also studied and the results show that these are predictable and controllable[9,10].

From a different perspective, detailed pump actuation studies for optimized filtration are conducted. As a result, stable flow and low flow rate are found to be effective in microbridge reduction[11,12].

Further, microbridge is also found as a major defect contributor in organic EUV resists[13,14], indicating that filtration is critical also in the future processes.

Above results are based on studies in positive tone imaging (PTI) process. However, as shown in Figure 2, as microbridge is caused by undissolved material in the developers, different polarity on the filter membrane may be desired in recently expanding negative tone imaging (NTI) process. NTI employs organic developer (non polar) in contrast to PTI, which employs alkaline developer (polar). In this study, we focus on the NTI filter optimization and are conducting evaluation for optimized resist point-of-use filtration in NTI process in comparison to PTI. Additionally, newly developed specially cleaned filtration products, which has been found to be effective in wet particle reduction[15] are evaluated for microbridge reduction.



Bridge defect is an undissolved matter in developer, should exhibit different polarity between NTI (organic solvent) and PTI (alkaline). And different polarity of filter membrane may be required.

Figure 2 Schematic of bridge defect in line and space resist pattern.

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2. EXPERIMENTAL

2.1 Photoresist preparation

Topcoat less 193 nm photoresists for NTI and for PTI are used for the testing. For the purpose of enhancing defectivity, simplified filtrations are employed in the resist preparation for both chemistries.

2.2 Test filters

Table 1 and Table 2 show the filter samples tested at the point-of-use of photoresist coating. All the test filters are Pall PhotoKleen* EZD-2 (single filtration area) and EZD-2X (double filtration area) filter capsules. Membrane material such as Nylon 6,6 and High density polyethylene (HDPE), filtration area and enhanced cleaning (-XP option), which reduces organic extractables, are the test variables.

Table 1 Test filters for NTI

No.	Membrane material	Filter rating (nm)	Filtration area (Single=710 cm^2, Double=1000~1300 cm^2)	Enhanced cleaning (-XP)
1	Nylon 6,6	20	Single	No
2	Nylon 6,6	20	Double	No
3	HDPE	5	Double	Yes
4	Nylon 6,6	20	Double	Yes

Table 2 Test filters for PTI

No.	Membrane material	Filter rating (nm)	Filtration area	Enhanced cleaning (-XP)
1	Nylon 6,6	20	Double	No
2	HDPE	5	Double	Yes
3	Nylon 6,6	20	Double	Yes

2.3 Lithographic conditions

Using SOKUDO RF^{3S*} coater/developer, photoresist is spin-coated on an organic BARC layer on a 300 mm wafer. The filtration during the resist dispensing is conducted with a 0.5 ml/sec. constant flow driven by tube-phragm dispense pump. ASML TWINSCAN* XT1700i 193 nm immersion exposure tool connected with the SOKUDO RF^{3S} is used to resolve 45 nm half pitch line and space (L/S) pattern. Resist thickness is 85 nm. Above conditions are applied for both NTI and PTI. n-butylacetate is used for a developer in NTI and 2.38% tetramethylammoniumhydroxide (TMAH) aqueous solution is used for a developer in PTI.

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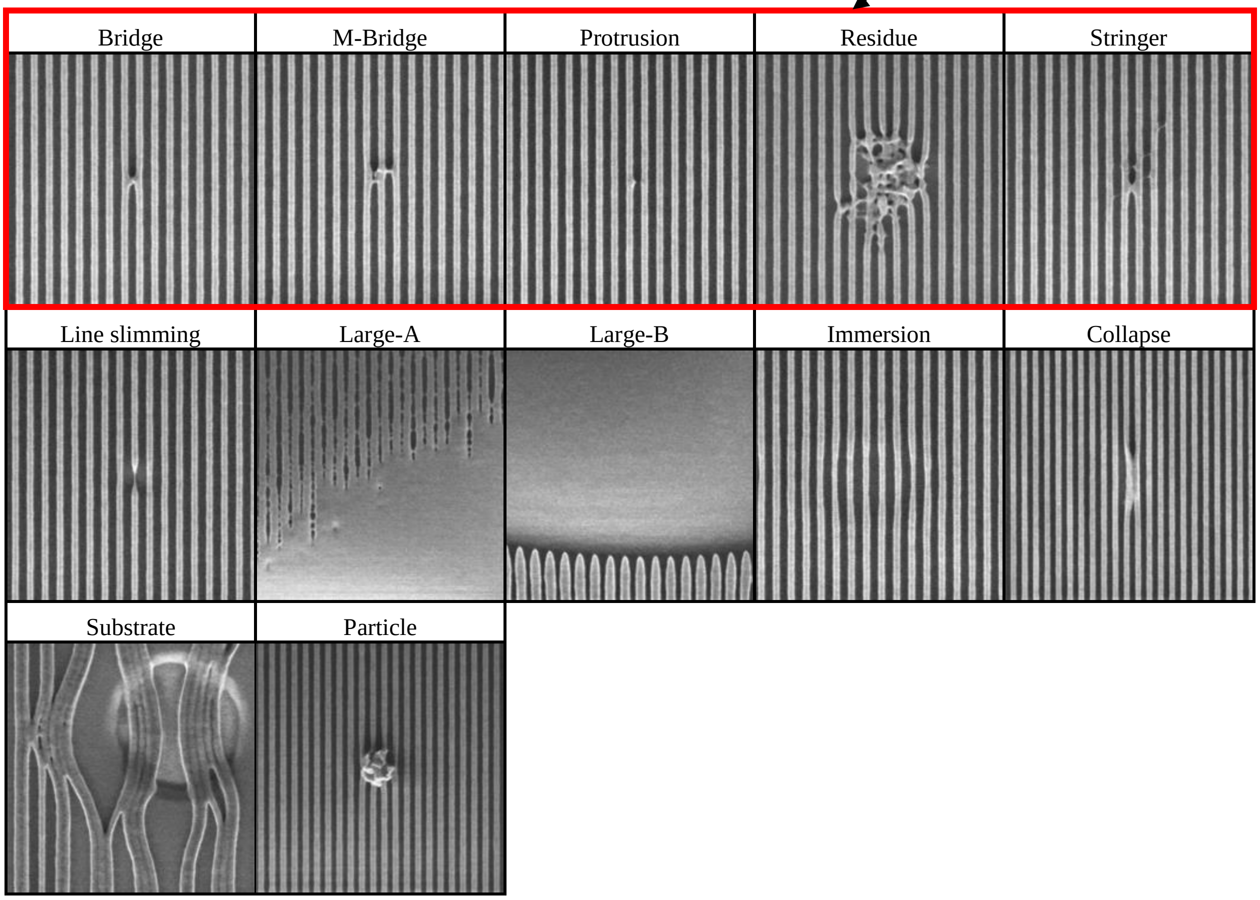
2.4 Filter start-up

Defectivity immediately after filter installation is known to show higher counts, then decreases with throughput of the resist. This is probably due to microbubbles, handling contamination and initial cleanliness of filter. In order to evaluate practical performance of the filter after filter start-up completion, 2000 ml of the initial resist throughput is discarded with repeating dummy dispensing, then a wafer is processed with the condition described in the previous section. The wafer processing is continuously conducted at dummy dispense throughputs of 3000 ml, 3050 ml, 3300 ml, 3500 ml and 3800 ml. Each 4 wafers per one processing are used to evaluate repeatability.

2.5 Defect classification

Applied materials UVision* 5 and SEMVision* G4 are used for defect inspection. Observed defects in NTI are shown in Figure 3. Same defects are observed in PTI. Five defect modes such as 1. Bridge, 2. M-Bridge, 3. Protrusion, 4. Residue and 5. Stringer bridge are known to correlate with filtration and picked up for quantitative comparison.

Figure 3 Defect classification



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3. RESULTS AND DISCUSSIONS

3.1 Defect classification

Figure 4 shows overall (all filters total) breakdown of filtration related defects at 3800 ml throughput. Bridge defect is dominant for both in NTI and in PTI with higher dominance in NTI. Defect type percentage between the test filters are not significant for both in NTI and PTI.

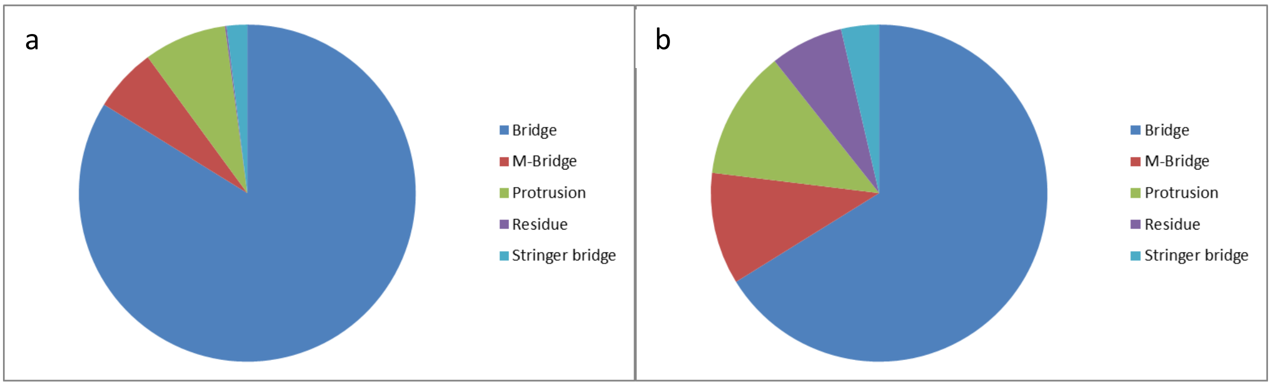

Figure 4 Overall defect classification breakdown. a: NTI, b; PTI.

3.2 Filter start up

Figure 5 shows filtration related defect density (total of five filtration related defects in Figure 3) as a function of resist throughput. Initially, defect density decreases with throughput then stabilizes at a point. Estimated stabilized point for NTI is 3300 ml and for PTI is 3550 ml. To utilize the results as much as possible, the stabilized result totals, boxed in red are used hereafter for comparison for statistical reliability.

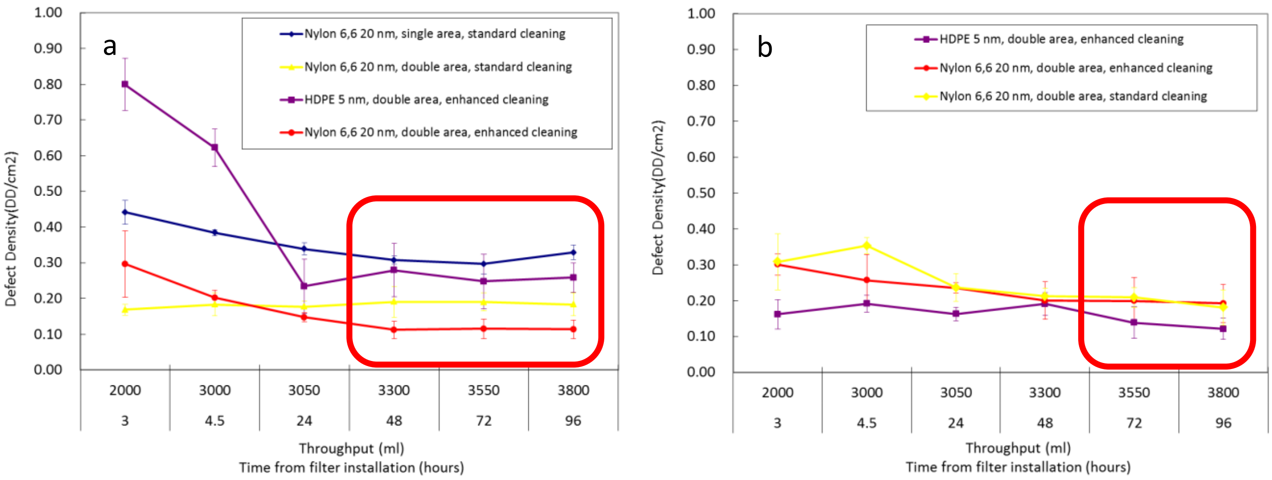

Figure 5 Filtration related defect density as a function of resist throughput. a: NTI, b; PTI. Average of four wafers. Error bar is standard deviation. The results boxed in red is used for comparison.

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3.3 Filter comparison -Negative tone imaging-

3.3.1 Overall filter comparison

Figure 6 shows defect density average from throughput 3300 ml to 3800 ml. The results on variables are discussed independently in the following sections.

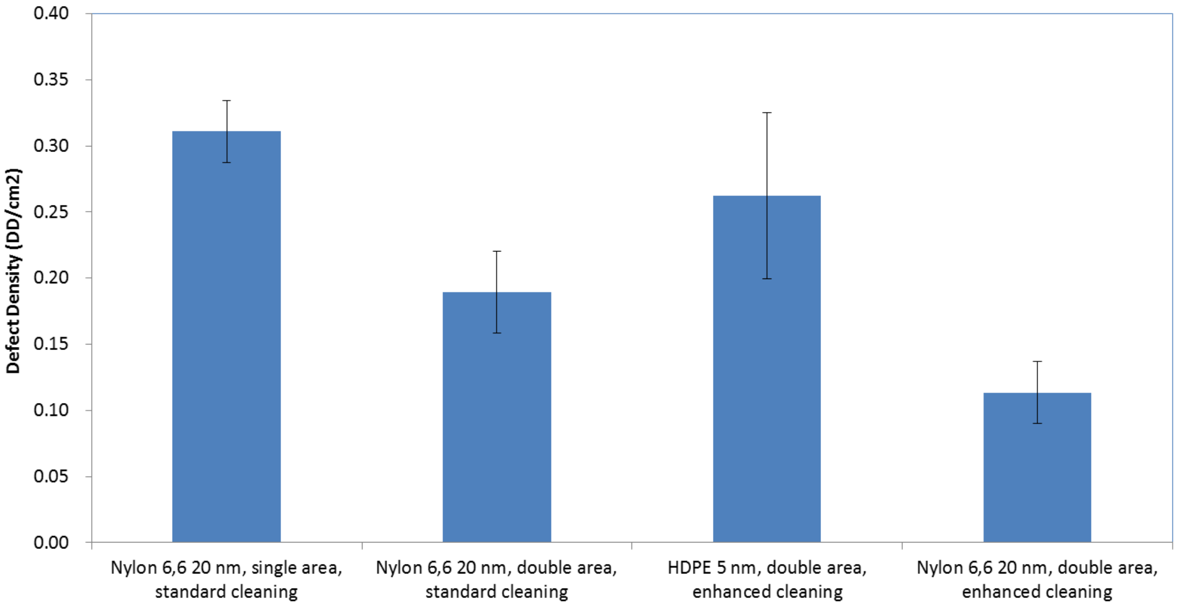

Figure 6 Filtration related defect density in NTI. Throughput 3300 ml to 3800 ml total. Error bar is standard deviation. n=11~12.

3.3.2 Filtration area

Figure 7 shows an effect of filtration area on filter related defect density in NTI. As a result, significant reduction of defect density is observed in employing double filtration area. In constant flow filtration, double filtration area halves filtration pressure and also doubles contact time between gels and filter membrane. The results prove a prediction concluded in our previous study [7] using a simulated gel challenge test. The previous study indicated that reducing differential pressure and extending contact time are effective to enhance gel removal.

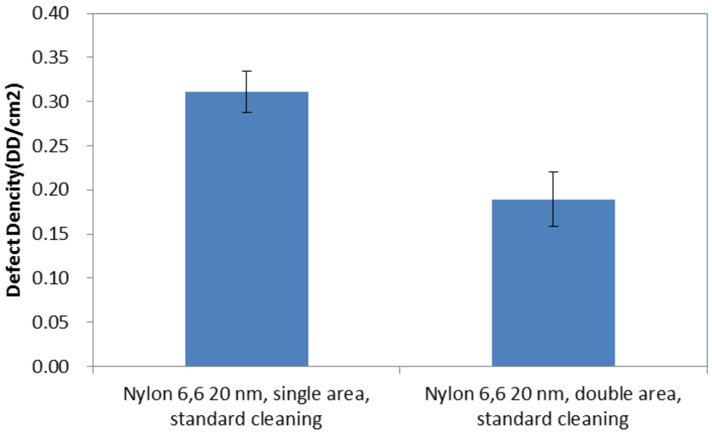

Figure 7 Effect of filtration area on filter related defect density in NTI. Throughput 3300 ml to 3800 ml total. Error bar is standard deviation. n=12.

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3.3.3 Enhanced cleaning

Figure 8 shows an effect of cleaning option on filter related defect density in NTI. As a result, significant reduction in defect density is found in filter with enhanced cleaning. The enhanced cleaning intrinsically reduces organic extractables. The result indicates that the some of the organic extractables from the filter impact defect density in the NTI process.

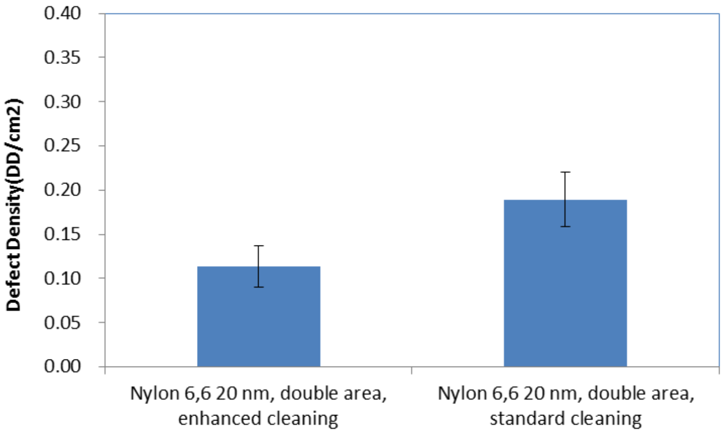

Figure 8 Effect of cleaning option on filter related defect density in NTI. Throughput 3300 ml to 3800 ml total. Nylon 6,6 enhanced cleaning vs. Nylon 6,6 standard cleaning. Error bar is standard deviation. n=12

3.3.4 Nylon 6,6 vs. HDPE

Figure 9 shows an effect of membrane material on filter related defect density in NTI. As a result, defect density is lower in Nylon 6,6 than HDPE. The results suggest that adsorption of the defect precursor in the resist on the Nylon 6,6 membrane is stronger than on the HDPE membrane.

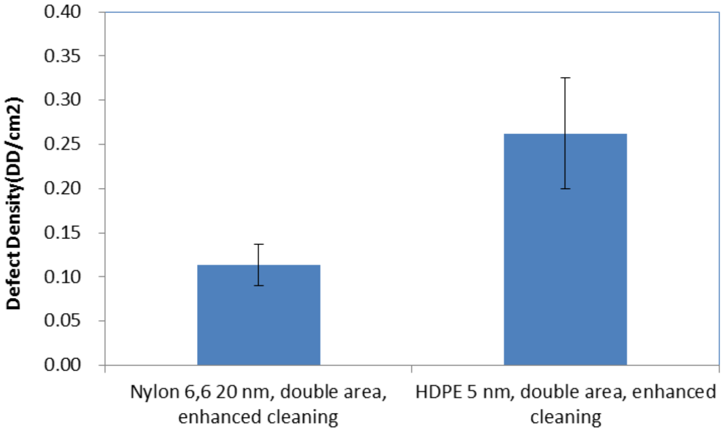

Figure 9 Effect of membrane material on filter related defect density in NTI. Throughput 3300 ml to 3800 ml total. Nylon 6,6 enhanced cleaning vs. HDPE enhanced cleaning. Error bar is standard deviation. n=12 for Nylon 6,6 and n=11 for HDPE.

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3.4 Filter comparison -Positive tone imaging-

3.4.1 Overall filter comparison

Figure 10 shows filter related defect density average from throughput 3550 ml to 3800 ml in PTI. The results on variables are discussed independently in the following sections.

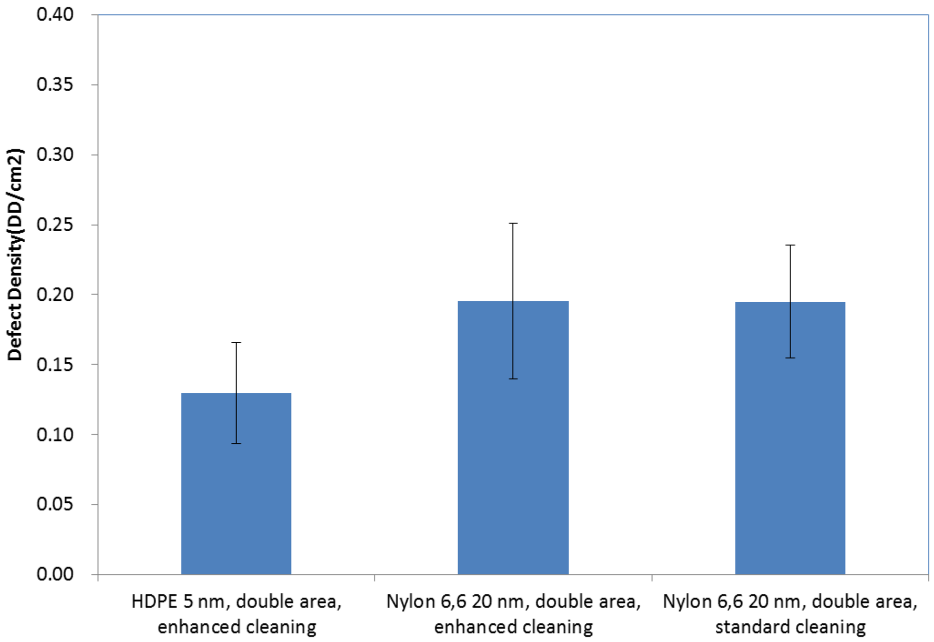

Figure 10 Filtration related defect density in PTI. Throughput 3550 ml to 3800 ml total. Error bar is standard deviation. n=8.

3.4.2 Enhanced cleaning

Figure 11 shows an effect of cleaning option on filter related defect density in PTI. As a result, no significant reduction of defect density is observed with the cleaning option.

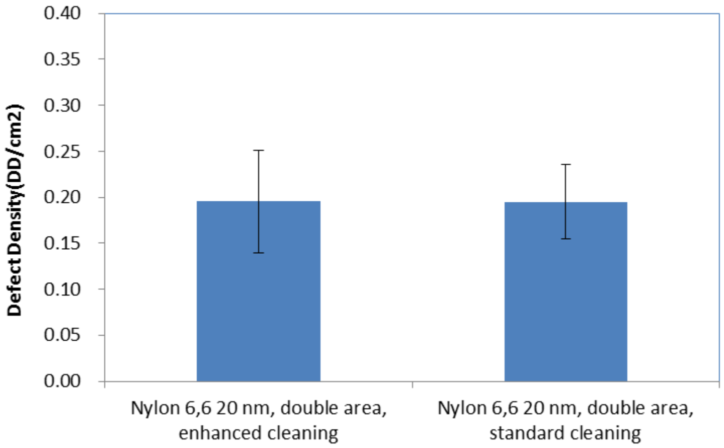

Figure 11 Effect of cleaning option on filter related defect density in PTI. Throughput 3550 ml to 3800 ml total. Nylon 6,6 enhanced cleaning vs. Nylon 6,6 standard cleaning. Error bar is standard deviation. n=8

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3.4.3 Nylon 6,6 vs. HDPE

Figure 12 shows an effect of membrane material on filter related defect density in PTI. As a result, defect density is lower in HDPE than Nylon 6,6. The results suggest two mechanisms. 1. adsorption of the defect precursor in the resist on the HDPE membrane is stronger than on the Nylon 6,6 membrane. And 2. higher sieving capability of the 5 nm rated HDPE filter surpassed 10~20 nm rated Nylon 6,6 filters. In this case, further improvement is expected with using finer HDPE filtration product, which has been already available in the market (Pall 2 nm rated HDPE filter).

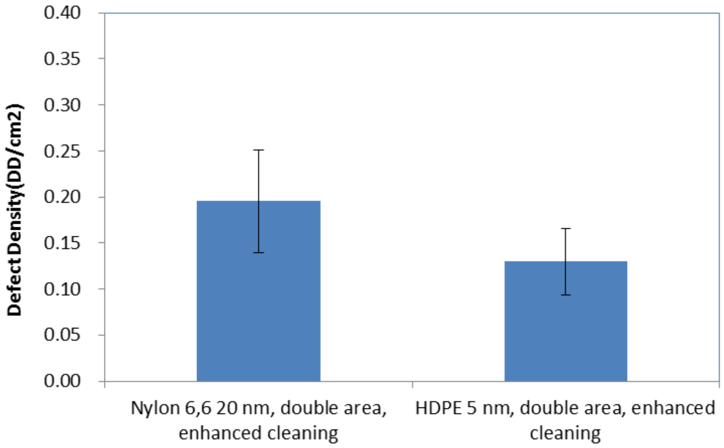

Figure 12 Effect of membrane material on filter related defect density in PTI. Throughput 3550 ml to 3800 ml total. Nylon 6,6 enhanced cleaning vs. HDPE enhanced cleaning. Error bar is standard deviation. n=8

3.5 Negative tone imaging vs. positive tone imaging

3.5.1 Enhanced cleaning

Enhanced cleaning results of Figures 8 and 11 are compiled in Figure 13. Enhanced cleaning of the filter is effective only in NTI. In NTI, the incremental in the standard cleaning should be due to some organic extractables. The mechanism for the PTI cannot be elucidated with the given results and will be studied further.

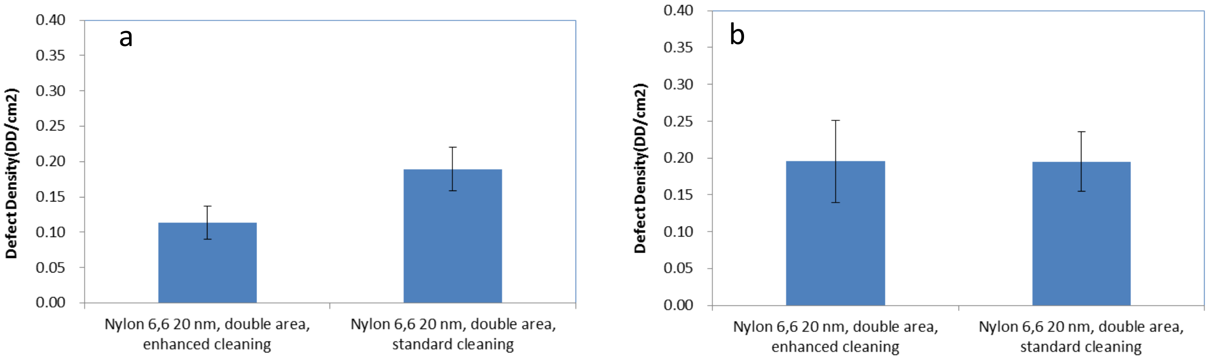

Figure 13 Filtration related defect density as a function of cleaning option. a: NTI, b; PTI. Compilation of Figures 8 and 11.

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3.5.2 Nylon 6,6 vs. HDPE

Results of Nylon 6,6 vs. HDPE for NTI and PTI are compiled in Figure 14. Nylon 6,6 performed lower defectivity in NTI. In contrast, HDPE performed better in PTI. Figure 14 suggests a mechanism in adsorptive point of view. In NTI, the defects should be hydrophilic because they are insoluble in hydrophobic n-butylacetate developer, therefore these hydrophilic defect precursors should be more adsorbed on Nylon 6,6 membrane during resist filtration. And in PTI, exactly the opposite mechanism can be suggested, hydrophobic defect precursors should be more adsorbed on HDPE membrane.

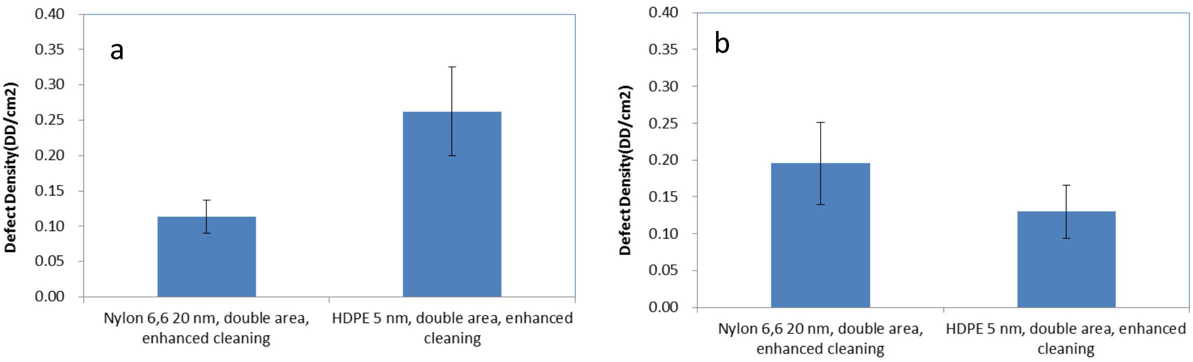
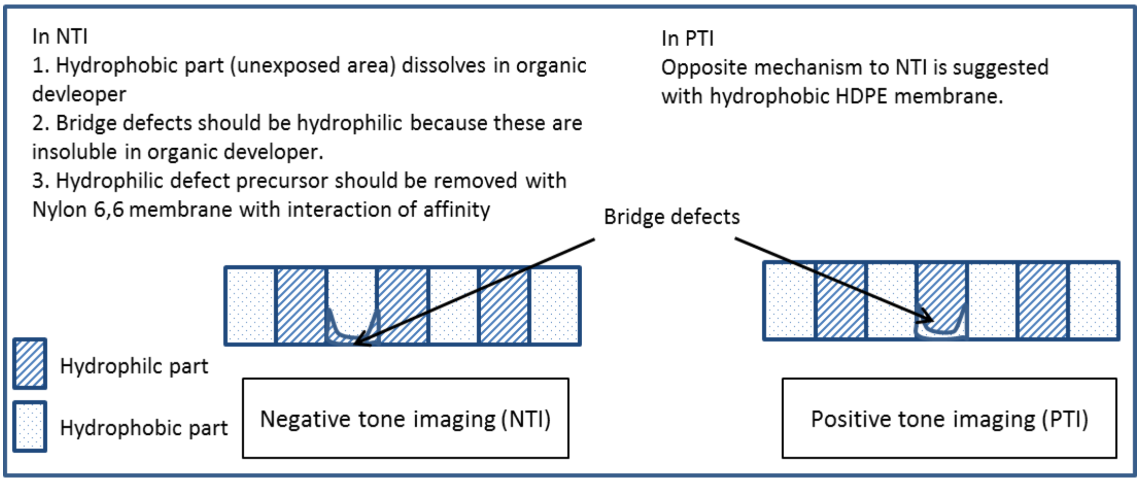


Figure 14 Filtration related defect density as a function of filter membrane. a: NTI, b; PTI. Compilation of Figures 9 and 12.



In NTI
1. Hydrophobic part (unexposed area) dissolves in organic devleoper
2. Bridge defects should be hydrophilic because these are insoluble in organic developer.
3. Hydrophilic defect precursor should be removed with Nylon 6,6 membrane with interaction of affinity

In PTI
Opposite mechanism to NTI is suggested with hydrophobic HDPE membrane.

Figure 15 Suggested defect polarities and mechanisms adsorptive filtrations in NTI and PTI.

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4. CONCLUSION

The test results suggested appropriate filtrations in both NTI and PTI processes. In NTI, enlarged filtration area, enhanced filter cleaning and Nylon 6,6 adsorption have significant impact in reducing bridge defects. In PTI, using 5 nm rated HDPE filter is effective, indicating that further improvement is expected with using 2 nm HDPE filter. A theory suggested in previous study in enhancing gel retention with reducing differential pressure and with increasing contact time is proven practically in the current NTI test. Contrast of preferable membrane polarity between NTI and PTI is explained with the suggested polarity of the defects. With these findings, appropriate filtration can be recommended for end users. The findings also will be utilized in next generation filter development.

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