Defectivity modulation in EUV resists through advanced filtration technologies

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ABSTRACT

The availability of EUV lithography is the mainstream for resolving critical dimension of the advanced technology nodes, currently in the range of 18nm and below [1]. The first insertion of EUVL into manufacturing utilizes chemically amplified resist (CAR) [2]. The filtration of CAR, both at bulk and point-of-use (POU), has already demonstrated in ArF and ArF immersion lithography to play a significant role for microbridges reduction essentially by removing hard particle and gels [3-6]. With respect to ArFi, EUV is bringing new challenges not only for the achievement of the required line roughness, sensitivity and resolution, but also for the need of a substantial reduction of defects such as line collapse, microbridges and broken lines.

In this study, it demonstrated the ability of utilizing novel POU filtration to modulate microbridges and achieving superior start-up behavior, both crucial for enabling EUVL at high volume manufacturing. Different POU filters were tested at the imec EUV cluster comprised of TEL CleanTrack LITHIUS Pro-Z and ASML NXE:3400B. The start-up performance, assessed by measuring defects down to 19nm size as a function of the flushing solvent volume, has shown the fast achievement of attaining a stable baseline. Lithography experiments targeting reduction of on-wafer defectivity, carried out with commercially available photoresists, have consistently shown a substantial reduction of after resist development (ADI) and after resist etch (AEI) microbridges on a 16nm L/S test vehicles. The effect of membrane physical intrinsic designs and novel cleaning of POU devices are discussed.

Keywords: EUV Lithography, microbridges, POU filtration

1. INTRODUCTION

The introduction of EUV lithography, which still largely utilizes CAR photoresists [1-2], has dramatically reduced the tolerance for defectivity [4-5]; therefore, materials and equipment suppliers are constantly required to increase the cleanliness of their products and processes. Within this landscape, filtration of lithographic materials has become extremely critical. While IC high volume manufacturers evaluate filter performance at increasing sensitivity, filter designers must deal with new challenges, such as: i) achieving a simultaneous retention of contaminants different in nature, i.e.: gels [3-6], metals and hard particles, by constantly developing new media; ii) coping with reduced critical size of contaminants by optimizing media’s physical morphology; iii) increasing requirements for continuously improvement in cleanliness, starting from raw materials to final devices. In this study, some critical parameters were identified which enable POU filtration to effectively mitigate the occurrence of line bridges on EUV line/space patterns of 16nmHP.

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2. EXPERIMENTAL

The newly developed high-density polyethylene (HDPE) XPR3 POU filter was compared to a commercially available product (both PhotoKleen EZD-3XL). The devices were characterized with a variety of analytical methods to assess media retention, extracted metals and organics, liquid particles, pressure and flow characteristics. A detailed description of these methods is not relevant for the present discussion. The performance of each device was then tested on bare silicon and pattern wafers, both in solvent and photoresist.

Flush-up behavior is assessed on a TEL Cleantrack LITHIUS Pro-Z coat-develop system, by systematically dispensing a controlled amount of RER650 (Fujifilm) on bare silicon wafer. Defects larger then 19nm were measured by a KLA SP5-XP system.

All lithography work was carried out on the imec EUV cluster, comprising a TEL CleanTrack Lithius Pro-Z and an ASML Twinscan NXE-3400 B scanner. All the lithographic materials utilized in this study, such as chemical amplified photoresist (CAR), spin-on carbon (SOC) and spin-on glass (SOG) (all provided by JSR), and organic underlayer (UL) (provided by Brewer Science International), are imec POR materials.

Pattern wafers for defectivity study were prepared with a 16nm line/space pattern. For after development inspection (ADI), Si/Underlayer/CAR wafers were used; for after etch inspection (AEI), Si/SiN/SOC/SOG/CAR wafers were used. Defects were inspected by a KLA 2935 system and reviewed by a KLA eDR7380 SEM.

3. RESULTS AND DISCUSSION

The effects of design and cleanliness of POU filtration on defectivity are discussed in this section.

3.1 Effect of membrane design

The normalized pore size distribution of the XPR3 filter (left), compared to the reference (right), is shown in Figure 1.

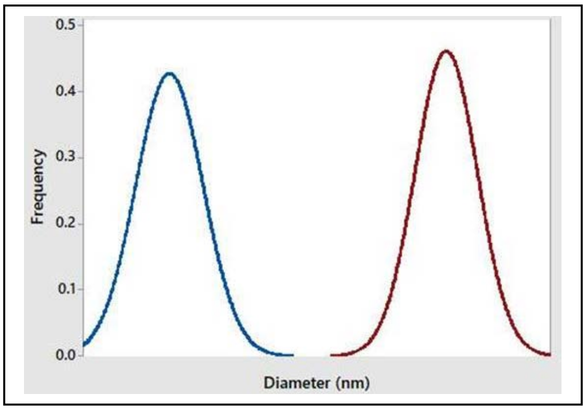

Figure 1. Comparative pore size and distribution in normalized scale of the XPR3 filter (left) v. reference (right).

The new HDPE membrane was designed to have a finer pore size, which is expected to improve defects retention, as demonstrated by on-wafer results presented in the next paragraphs. Furthermore, a reduction of 50% in pressure drop was achieve on the XPR3 device compared to the reference one, as reported in Figure 2.

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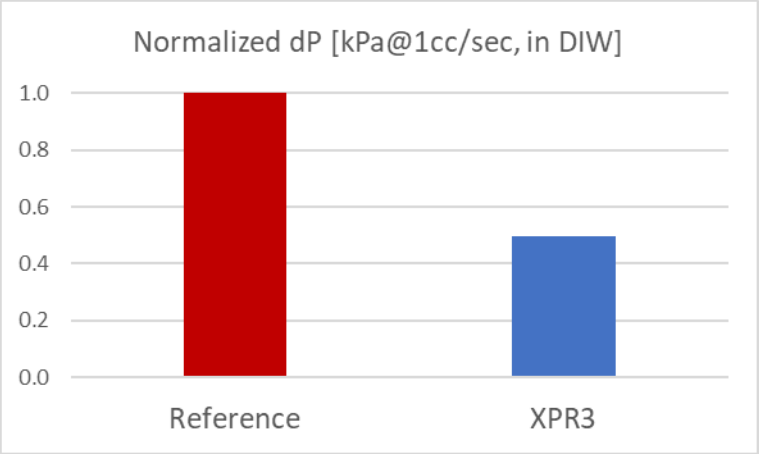

Figure 2. Normalized pressure drop measured in DIW at 1cc/sec.

3.2 Effect of device cleaning

To cope with the demanding defects tolerance imposed by EUV lithography, a new cleaning method was designed to reduce the content of organic compounds and particles on devices. Organics were extracted by soaking each device for a fixed amount of time. The solvent was then analyzed by a GC-MS system, the breakdown of organics was acquired and the normalized total amount for each device was calculated and reported in Figure 3.

From this comparison, it is demonstrated the dramatic effect of the new cleaning on extracted organics, which total content has dropped by 60%.

The cumulated count of particle larger than 20nm was measured on each device by using a liquid particle counter in DIW. The results are compared in Figure 4, where the LPC traces showed a drop of 45% on the new HDPE XPR3 filter compared to the reference.

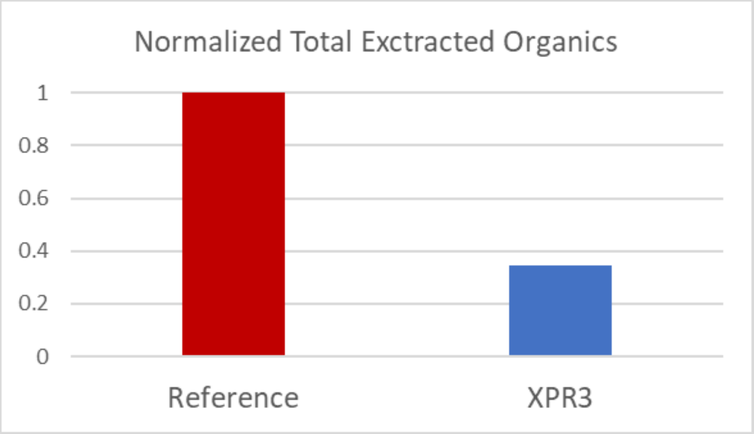

Figure 3. Normalized total extracted organics, obtained by soaking each filter for a fixed amount of time, and analysing the extracted by GC-MS.

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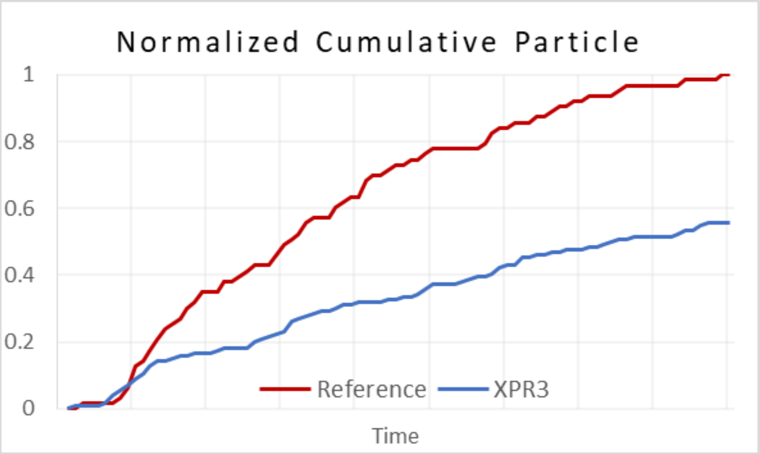

Figure 4. Normalized cumulated particle >20nm, measured by LPC in DIW.

3.3 Testing devices on wafers

Start-up behavior, coated particle, after development defect (ADI) and after etch defect (AEI) were studied on both devices as described in the following paragraphs.

3.4 Start-up behavior

The purpose of this test is to evaluate the filter start-up behavior. Key factors affecting the device start-up are particle cleanliness, extractable organics and membrane wettability with the solvent [6]. Each filter was installed and primed in accordance to the imec POR procedure. The start-up test was then carried out by dispensing a regular amount of thinner RER650 on bare silicon wafers, and by measuring the added defect larger than 19nm. The results are reported in Figure 5 in a normalized scale, where each data point represents the average of two test wafers. The plot shows a clear improvement achieved with the new HDPE XPR3 filter, both in terms of achieving time-to-baseline and stability of the baseline itself.

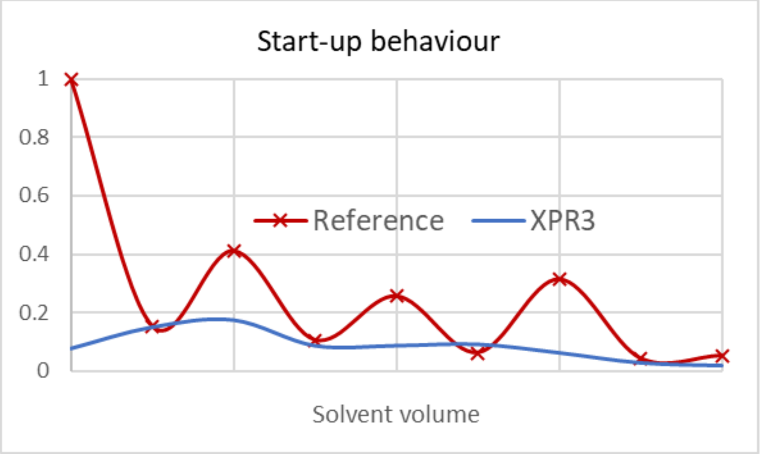

Figure 5. Normalized count of defects larger than 19nm, collected on bare silicon wafers at the indicated flushing solvent volume.

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3.5 Coated defects

Coated defects were evaluated by dispensing a controlled amount of resist on bare silicon wafers and by measuring defect larger than 47nm. The test was repeated for three times over one week. Results are reported in Figure 6, where each dot is the average of two testing wafers. The new HDPE XPR3 filter performs consistently better than the reference at the investigated measured particle size.

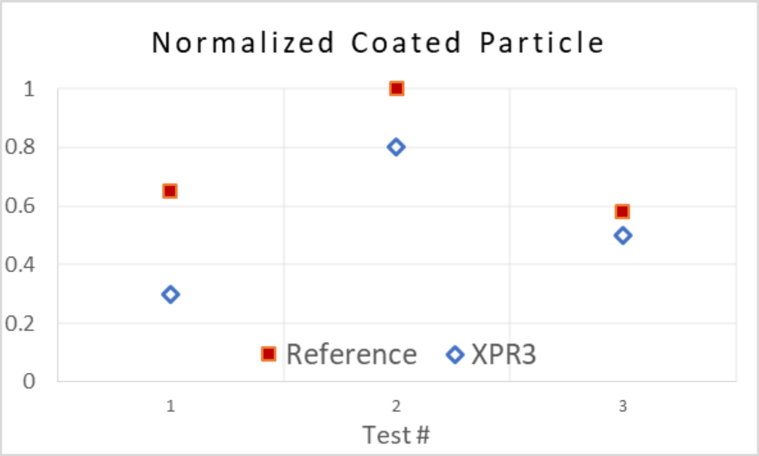

Figure 6 Normalized count of particles coated on bare silicon wafer and measured by SP5-XP at a size larger than 47nm.

3.6 After Development Inspection (ADI) defects

The last two evaluations were aimed at the count and classification of defects after resist development (ADI) and after resist etch (AEI). The defect counts were obtained by scanning the test wafers on a KLA 2935 tool, and the defect morphology was study by KLA eDR 7380 SEM tool. Normalized ADI results are reported in Figure 7, where each bar represents the averaged defect count of two test wafers. The defect classification revealed an equal amount on SEM non-visible on both set of wafers, which were then removed from the analysis. ADI defects are typically classified in filtration related-defects, i.e.: single and multi-bridge, and non-filtration related-related, i.e.: below pattern, underlayer residues, particles on top. As results of a more retentive and cleaner membrane, the new HDPE XPR3 filter showed a dramatic improvement on both single and multiline bridges. A further characterization of below pattern defects will be part of a future study.

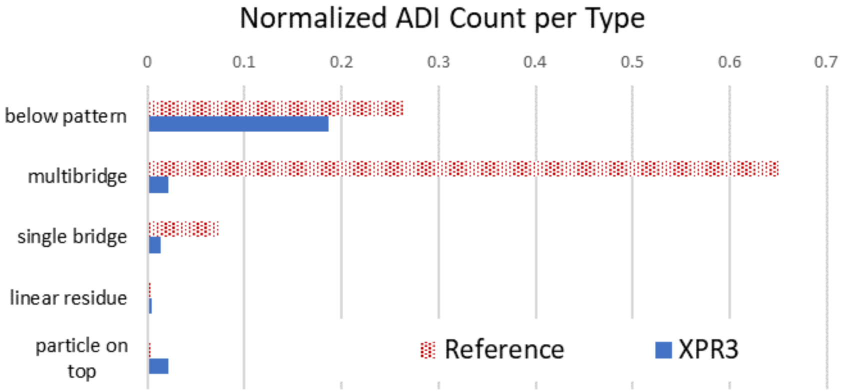

Figure 7 Normalized <u>A</u>fter <u>D</u>evelopment <u>I</u>nspection (ADI) defect pareto. An equal amount of SEM non visible defect was observed on all wafers and was removed from the plot.

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3.7 After Etch Inspection (AEI) defects

After etch inspection (AEI) test wafers (Si/SiN/SOC/SOG/CAR) were exposed both at a nominal dose and dose matrix, the latter used to identify the so called “microbridges floor”, as documented in [7]. The pattern was transferred by dry etch into the SiN layer, and post-etch residues (i.e.: polymers) were removed by a standard wet chemical cleaning. The normalized defect density as a function of line CDs is shown in Figure 8 which demonstrate that the new HDPE XPR3 filter decreases the “microbridges floor” by 75%, with a minimal impact on the process window.

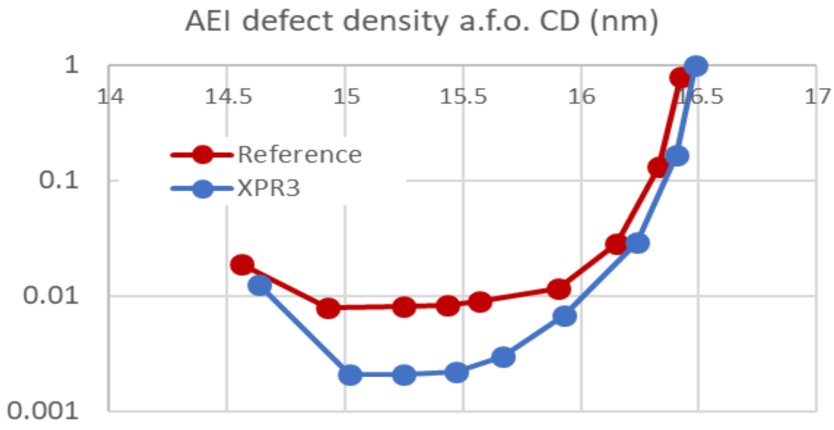

Figure 8. Normalized After Etch Inspection (AEI) defect density as a function of line CD (nm), in logarithmic scale.

The defect pareto obtained from the uniform dose test wafers revealed that the main occurrence of defects were single bridges. Normalized results are shown in Figure 9.

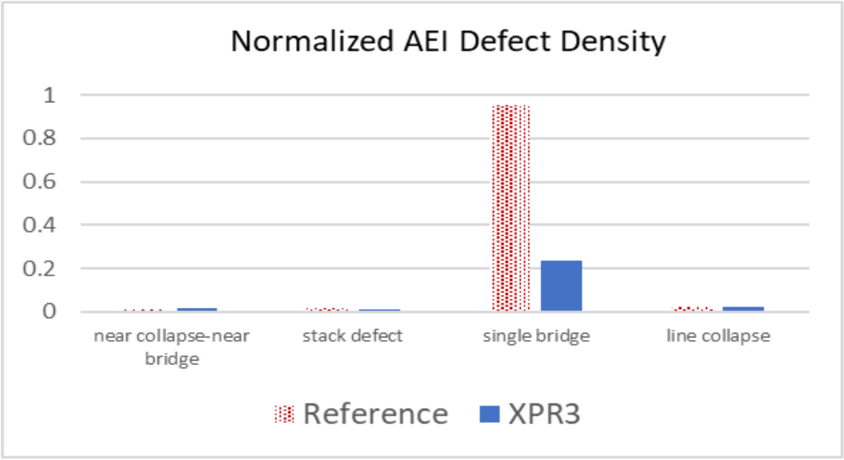

Figure 9. Normalized After Etch Inspection (AEI) defect density by defect type.

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ADI and AEI defects are typically classified as filtration related, such single and multiple bridges, and non-filtration related, such as pattern collapse, line wiggling and broken line. The library used in this work for ADI and AEI defects classification is reported in Figure 10.

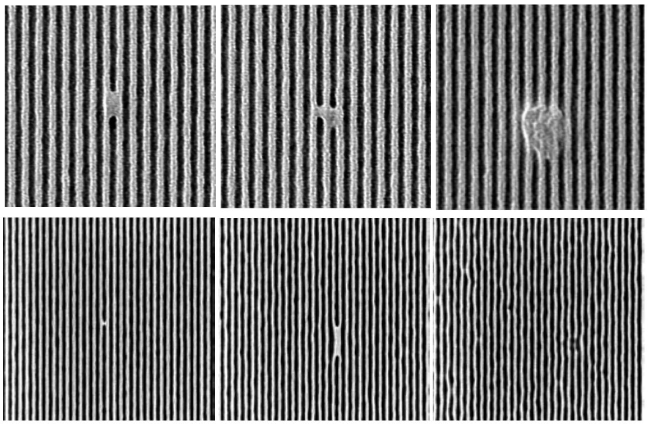

Figure 10. Main defectivity modes measured by KLA-2935 and classified by eDR7380. **ADI** (top): single bridge (left), multiline bridge (center), below pattern (right). **AEI** (bottom): single bridge (left), pattern collapse (center), line wiggling (right).

4. CONCLUSIONS

This study provided a better understanding of key modulators of EUV defectivity after resist development and etch, from a POU filtration perspective. The synergic effects of membrane design and device cleaning have been proven to dramatically decreasing both ADI and AEI defects. These factors coupled with achieving faster time-to-baseline and high flow (low dP), are essential for the implementation of EUV lithography at a high-volume manufacturing scale.

REFERENCE

[1] Lazzarino, F., “EUV pattering: Challenges and Opportunities,” SMC Korea 2019.

[2] Nakagawa, H., et al., “Recent EUV resists towards high volume manufacturing,” Journal of photopolymer science and technology 27(6), 739-746, (2014).

[3] Umeda, T., et al., "Filtration condition study for enhanced microbridge reduction," Proc. SPIE 7520, 75201K (2009).

[4] Umeda, T., et al., “Defect reduction by using point-of-use filtration in new coater/developer,” Proc. SPIE 7273, 72734B (2009).

[5] Sevegney, M., et al., “Microbridge and e-test opens defectivity reduction via improved filtration of photolithography fluids,” Proc. SPIE 7273, 72730O (2009).

[6] Umeda, T., et al., “Start-up performance and pattern defectivity improvement using 2nm rated Nylon filter developed with lithography filtration expertise,” Proc. SPIE 16960 1696018 (2019).

[7] Foubert P., et al., “Imec’s defect reduction strategies for EUV single exposed 32nm pitch line and space patterns”, SPIE EUV photomask technology and EUV lithography (2019).

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