High performance filtration for bulk materials: a novel HDPE membrane filter designed for EUV Lithography

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ABSTRACT

Extreme Ultra-Violet (EUV) lithography is pushing material suppliers to provide the cleanest possible products for tight quality standards. The emphasis on minimizing residual particles, metals, and organics coming from materials and equipment continues to increase. Filter design and its key sub-components such as membrane continue to play a significant role to enhance performance in EUV lithography by reducing defectivity. This necessitates an improvement in retention and cleanliness for both bulk and point-of-use (POU) filters. While POU filtration targets high retention, typically achieved by membrane's reduced pore size, the main requirement of bulk filtration is maximizing the amount of material recirculated through the filter per unit of time and is achieved with improved tortuosity and well-defined pore structure.

In this study, we present a novel HDPE filter specifically designed to provide a high flow (lower differential pressure) without sacrificing retention characteristics. The new membrane was assembled in a POU filter format and compared head-to-head with a state-of-the-art HDPE membrane filter for POU application. The flow performance was assessed by differential pressure (dP) measurement, which showed an enhanced performance benefit of dP reduction by 50% compared to the reference filter, while all other test parameters are improved or at least comparable. The filter cleanliness was quantified by liquid particle counter (LPC), GC-MS, and ICP/MS measurements. Finally, comparative defect data was obtained from the blanket and pattern wafers, prepared on imec EUV cluster comprised of TEL Clean Track LITHIUS Pro-Z and ASML NXE:3400B with a 16nm L/S test vehicle.

KEYWORDS: EUV Lithography, microbridges, bulk filtration, POU filtration.

1. INTRODUCTION

The introduction of Extreme Ultra-Violet (EUV) lithography in high volume manufacturing urges materials suppliers to provide the cleanest possible products in order to cope with stringent defect requirements. Emphasis on minimizing residual particles, metals, and organics coming from coating, developer and rinsing materials, as well as filters, is dramatically increasing. This critical cleanliness metric drives for the improvement in performance for both bulk and point-of-use (POU) filters as part of the contributing factor.

POU filtration is a single-pass process, where materials are filtered once, and then directly dispensed on the wafer surface. As any contaminations added at this step can lead to a significant reduction in yield, the goal of POU filtration is maximizing retention with the cleanest possible device. Bulk filtration is a multi-step process, where materials are recirculated through a sequence of different filters at decreasing pore size. The main requirement of bulk filtration is maximizing the flow, which is typically achieved with low differential pressure (dP) devices at the expense of retention.

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High-density polyethylene (HDPE) is the membrane of choice for several materials utilized in lithography, both for immersion and EUV applications. Pall sub-1nm HDPE (XPR3L) has already demonstrated excellent performance with status-of-the-art EUV photoresist [1]. In this study, the data of a novel HDPE membrane specifically targeting high flow and outstanding retention is presented. As shown in previous works [2, 3], and discussed in Section 4, we have modeled and implemented options to optimize retention without reducing membrane pore size. The novel membrane was assembled in a POU filter format and compared head-to-head with a state-of-the-art HDPE membrane filter for EUV application [1], with the intent of assessing any possible detrimental effect brought about by the improved differential pressure. While retention is comparable to our reference, a decrease of 50% in differential pressure was observed, which makes this product highly recommended for bulk filtration where EUV-grade retention is required

2. EXPERIMENTAL

Each filter was characterized by a variety of analytical methods to assess differential pressure, flow, liquid particles, extracted metals, and extracted organics.
The final performance of each filter was then tested on bare silicon and pattern wafers, both in organic solvent and photoresist. Lithography work was carried out on the imec EUV cluster, comprising a TEL CleanTrack Lithius Pro-Z and an ASML Twinscan NXE-3400B scanner. The 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 process-of-record (POR) materials. Pattern wafers for after-etch defectivity study were prepared with a 16nm line/space pattern on Si/SiN/SOC/SOG wafers coated with CAR. Defects were measured and characterized by a KLA 2935 broad band optical inspection system and a KLA eDR7380 SEM

3. RESULTS

The comparative data of XPR3L and HXPR3L collected both at the Pall Scientific Laboratory and imec are presented and discussed in this session.

1.1 Differential Pressure Measurement

The high flow XPR3L membrane is specifically designed for bulk applications in order to provide high flow without sacrificing retention. The new membrane was arranged in a POU format and compared with the reference (XPR3L). The differential pressure (dP) measured on both devices is shown in Figure 2. The dP values are normalized on the XPR3L value. Compared to the reference, HXPR3L allows a reduction of 50% of differential pressure.

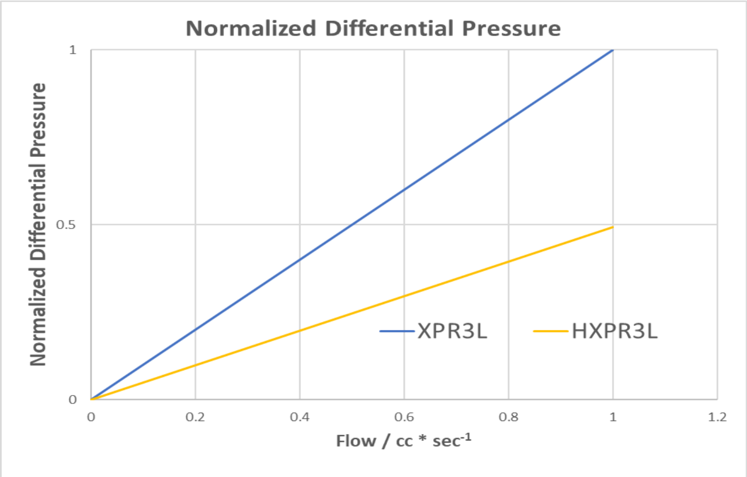

Figure 1: Comparative differential pressure of the status-of-the-art (XPR3L) and the novel high flow HDPE (HXPR3L).

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1.2 Liquid Particle Count (LPC)

Figure 2 shows the result of the liquid particle count (LPC) test, carried out in DIW. A PMS UDI-20 counter with a sensitivity of 20nm was utilized. No consistent deviations between the two filters are recorded, which is the first indicator of the high HXPR3L perfomance.

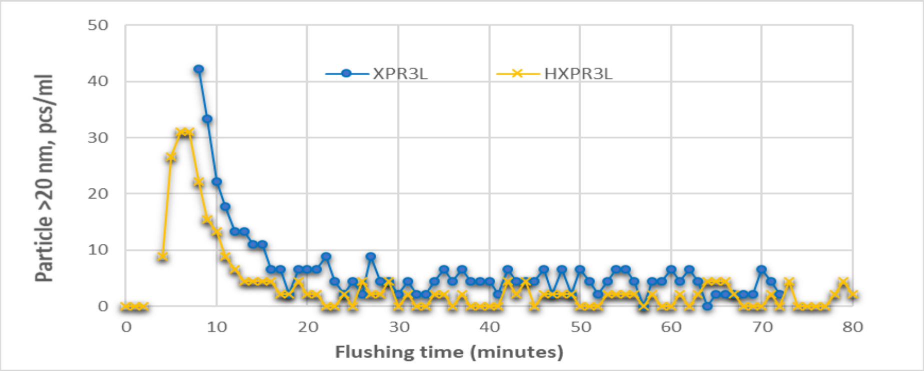

Figure 2: Comparative liquid particle count (LPC) obtained in DIW from XPR3L and HXPR3L filters.

1.3 Extracted organics and metals

To assess extracted organic compounds, both filters were soaked in a fixed volume of organic solvent, which was then analyzed by GC/MS. Extracted metals were obtained by soaking the filters in a fixed volume of DIW, which was then analyzed by ICP-MS. Standard libraries of 20 organic compounds and 22 metals were utilized on this test. Total extracted organics and metals are reported in Table 1, normalized on XPR3L's values.

Table 1. Total extracted organics and extracted metals, normalized on XPR3L's extractables.

Normalized Extractables	*XPR3L*	*HXPR3L*
Total Extracted Organics	1	1
Total Extracted Metals	1	0.86

1.4 After Etch Inspection (AEI) defectivity study

Comparative AEI defectivity data were collected within a timeframe of five months, in two different runs; each run included two uniform dose wafers and one dose-matrix wafer per filter. Defects were classified according to the defect library shown in Figure 3: single-line bridge, multiple-line bridge, pattern collapse, and near collapse.

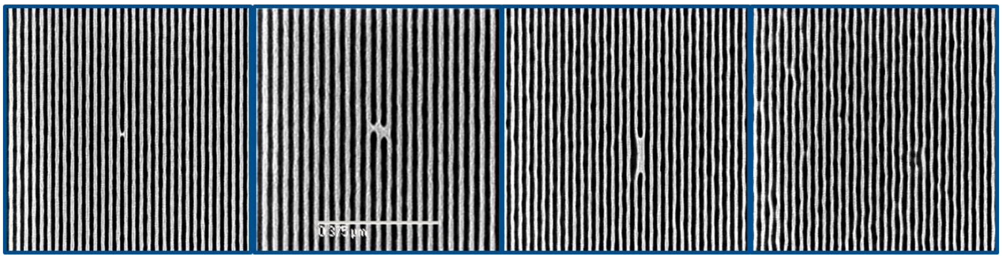

Figure 3: Defect classification, left to right: single-line bridges, multi-line bridge, pattern collapse, and near pattern collapse

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The analysis of multiple wafers showed that single-line bridge failure mode accounts for 95% of the total defectivity, the multiple-line bridge for 0.5%, pattern collapse for 3% and, near collapse for 1.5% (Figure 4).

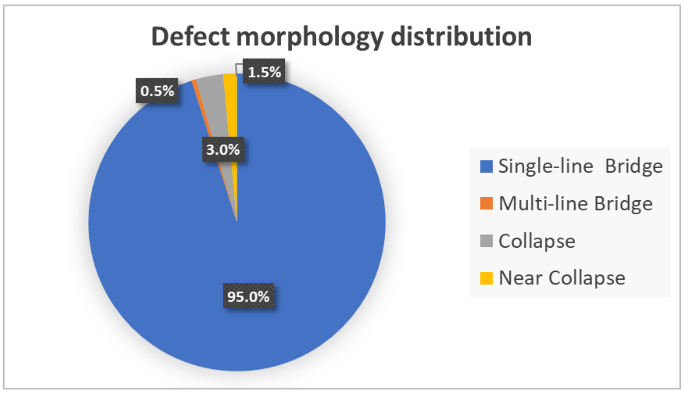

Figure 4: Defect morphology distribution.

The average defect density (DD, defect/cm2) for each run, normalized on XPR3L data, is shown in Table 2. The defect density as a function of line CDs is shown in Figure 5, on a logarithmic scale.

Table 2. Total defect normalized on XPR3L count.

Normalized Total Defect	*XPR3L*	*HXPR3L*
Run 1	1	1.09
Run 2	1	0.93

By comparing Table II and Figure 5, we can conclude that the new filter HXPR3L is equivalent in performance to XPR3L at the CDs of interest while allowing a 50% of differential pressure reduction, which makes the product specifically recommended for bulk application.

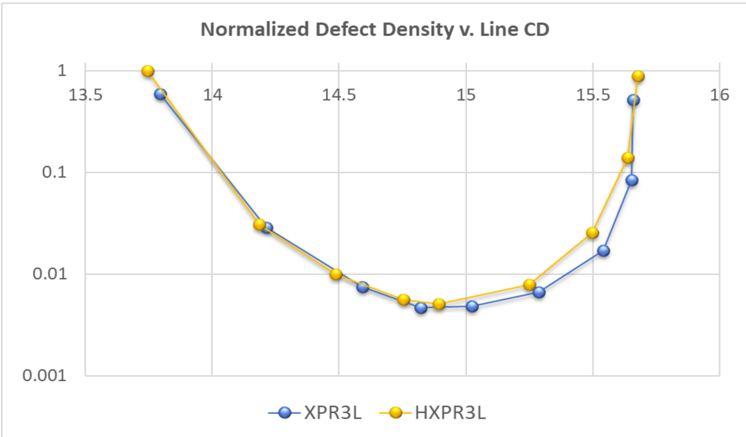

Figure 5: Normalized after etch inspection (AEI) defect density as a function of line CD. The plot is in logarithmic scale.

4. DISCUSSION

In the experimental part, we have shown that this high flow membrane achieves outstanding defect retention. The interpretation of this behavior is described in Figure 6. In filters with a very fine pore membrane, the relationship between flow and differential pressure is linear, which implies a laminar flow within individual membrane pores. In a laminar flow regime, a differential pressure is generated by shear force between the fluid molecules adsorbed on the pore wall and the fluid molecules in the stream. According to the equation shown in Figure 6, a lower differential pressure value generates a lower shear force that allows gel or particles to be effectively retained on the pore wall. Therefore, lower differential pressure means lower shear force that enables easier capture and retainment of gel particles on the filtration membrane.

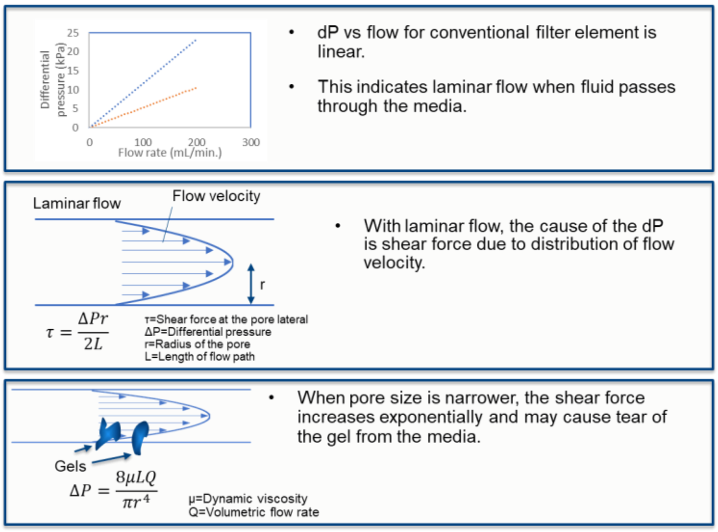

Figure 6: Model for enhanced particle retention by reducing flow-differential pressure in filtration.

5. CONCLUSIONS

In this study, we discussed the performance of a novel HDPE filter specifically designed for high-flow applications. The morphology of the membrane was designed to minimize the shear force within pores and to allow optimal retention of gels defects. An improved differential pressure makes this device suitable for the bulk filtration of lithographic materials in the EUV applications space, where outstanding retention is required.

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