Advanced lithographic filtration and contamination control for 14nm node and beyond semiconductor processes

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ABSTRACT

Two versions of a specific 2nm rated filter containing filtration medium and all other components produced from high density polyethylene (HDPE), one subjected to standard cleaning, the other to specialized ultra-cleaning, were evaluated in terms of their cleanliness characteristics, and also defectivity of wafers processed with photoresist filtered through each. With respect to inherent cleanliness, the ultraclean version exhibited a 70% reduction in total metal extractables and 90% reduction in organics extractables compared to the standard clean version. In terms of particulate cleanliness, the ultraclean version achieved stability of effluent particles 30nm and larger in about half the time required by the standard clean version, also exhibiting effluent levels at stability almost 90% lower.

In evaluating defectivity of blanket wafers processed with photoresist filtered through either version, initial defect density while using the ultraclean version was about half that observed when the standard clean version was in service, with defectivity also falling more rapidly during subsequent usage of the ultraclean version compared to the standard clean version. Similar behavior was observed for patterned wafers, where the enhanced defect reduction was primarily of bridging defects. The filter evaluation and actual process-oriented results demonstrate the extreme value in using filtration designed possessing the optimal intrinsic characteristics, but with further improvements possible through enhanced cleaning processes.

Keywords: Nano-filtration, contamination controls, microbridging defects, membranes, cleanliness

1. INTRODUCTION

New challenges and opportunities in process and design innovations continue to emerge in parallel to ever shrinking semiconductor device geometries and technology scaling beyond 14 nm [1]. Filtration technology plays a key role and must keep up with not only defect scaling, but with the need for performance far less impacted by contamination. Metals, particulates, fibrous defects, and residue defects in the photoresist dispense system have been significant yield detractors for IC manufacturing processes for years and have had a strong impact on various optical photolithography steps. Optimized filtration is needed to meet current, stringent defect tolerance to remove of <10nm size contaminants (Metals/Particles/Organics/NVR) from Chemicals [2]. Controls must be in place with respect to filter cleanliness, retention rating, nature of filter media/design, filtration rate, and controlled filtration pressure drop versus flux.

A wide variety of contaminant types may be responsible for causing wafer defects that impact yield, including particles, metals, organics, and non-volatile residues. Any of these may have multiple points of origin:

- Defects in starting materials
- Lithographic imaging process induced defects
- Pattern transfer defects
- Equipment induced defects

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One of the key means of addressing contamination control is the use of filtration at the nanometer scale (or "nano-filtration"). Development of nano-filtration suitable for such demanding service involves a variety of aspects that must be considered, as shown in Table 1.

Table 1. Aspects Associated with Developing Nano-Filtration for Advanced Technology Nodes

- **Advanced Manufacturing Process (AMP)**
  - Building Filters in Cleanrooms
  - Integrated Mfg. operations
- **Customized Cleaning Processes**
  - Trace Metals
  - Residual Organics
  - Particle Adders
  - Filter Start-up
- **Membrane Retention Metrology**
- **Advanced Membrane Technologies**
  - Finer Pore-sizes
  - Adsorption vs Sieving
  - Symmetric vs Asymmetric
- **Application Specific Filtration Processes**
  - TARC/ Topcoats
  - Immersion Resists / TC Less Resists
  - Developers – TMAH, nBA
  - Metal-Oxide EUV Resists
  - DSA

Addressing these aspects achieves the goal of providing filtration that is finer, cleaner, faster, and application compatible.

Filtration meeting current application demands in the lithography area achieves its primary function of removing contaminant by means of several filtration mechanisms:

- Sieving
- Adsorption
- Surface interactions
- Hydrophilic-hydrophobic balance
- Tortuous path

Pall Corporation provides filters containing a variety of different filtration media capable of achieving the required contamination removal for lithography. Figure 1 shows the chemical structures of three such media, HDPE, nylon-66, and polytetrafluoroethylene (PTFE), along with additional information on available ratings and cleaning innovations.

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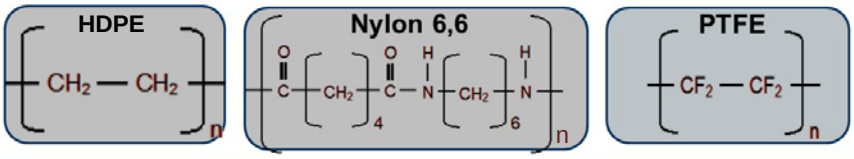

Pall Membrane Technologies	Products (Rated by GNP)	Cleaning Innovations
HDPE	≥2nm Commercial <2nm - Production	Standard, Express Clean (XP), Ultra Clean (XG)
Nylon 6,6	≥5nm –commercial 2nm – Pre-Production	Standard, Express Clean – XP,XN Extra Clean- CIP
PTFE	10nm – Commercial 5nm – Pre-Production	PFA Hardware, Express Clean

Figure 1. Finer membranes available from Pall Corporation for lithography applications (Note: "GNP" refers to gold nanoparticles)

Among the membrane attributes that may be considered in terms of impacting performance characteristics is the membrane morphology. In particular, certain media are conducive to being produced with a greater or lesser degree of asymmetry from the upstream to the downstream face of the medium. This is depicted in Figure 2.

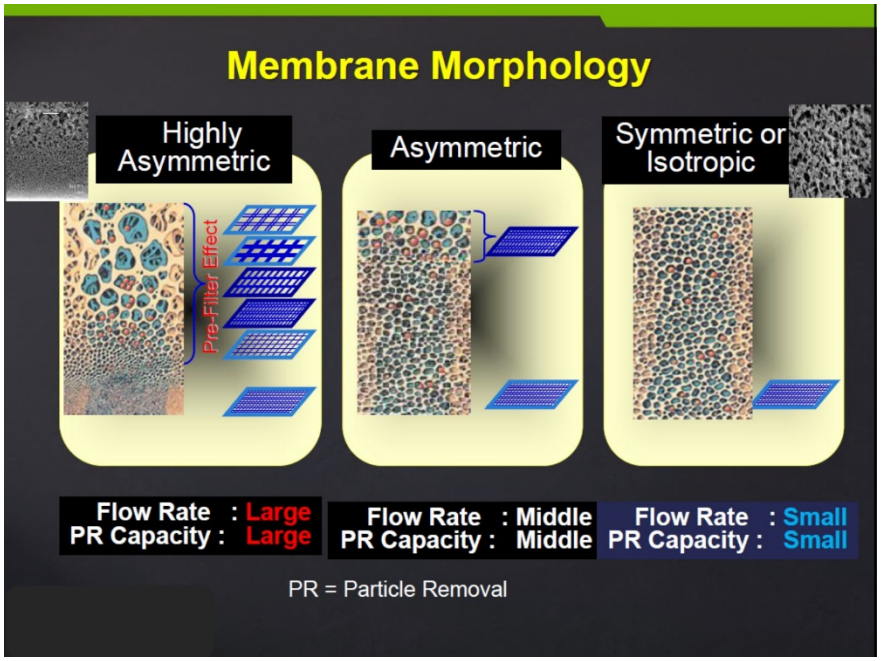

Figure 2. Different types of membrane morphology that may apply for filtration media used in lithography applications.

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While all the various aspects of membrane development, filter construction, and final filter processing impact the final product and how it works in the actual application, we have chosen to focus on one aspect in particular, namely cleaning processes that a filter may undergo. In the current case the filter selected was one containing HDPE medium possessing a 2nm particle retention rating. We seek to show that enhanced cleaning not only improves the intrinsic cleanliness of the filter in terms of extractables and particles, but also leads to improved performance in actual lithography application.

2. EXPERIMENTAL

Two versions of 2 nm rated filter containing HDPE filtration medium, with all other components also of HDPE construction, were evaluated. One, referred to here as "UG2," was subjected during its manufacturing to a standard cleaning process, while the second, called "XG2," had been subjected to ultra-cleaning. Testing of initial filter cleanliness included evaluations of each filter's levels of metal and organic extractables, and of particle release upon installation. In the application-oriented segment of testing, series of blanket and patterned wafers subjected to dispense of 193nm photoresist (PR) through each version of filter, installed at point-of-use (POU) were analyzed for defects. Defect level was monitored over time for each filter version and for each wafer type.

2.1 Extractables Testing

Samples of each version of filter, in capsule form, were filled with ultrapure deionized water (DIW) for metal extractables and with an organic solvent for non-volatile residue and left soaking for 24h, at room temperature. At the end of the extraction period, the fluids filling each capsule was analyzed for *i.*) levels of 22 metals via inductively coupled plasma-mass spectrometry (ICP-MS, Agilent), and *ii.*) total organics via qualitative determination of non-volatile residue.

2.2 Particle Rinse-in Testing

Capsules of each filter type were individually subjected to 300 mL/min recirculation of a 70/30 blend of propylene glycol monomethyl ether (PGME) and propylene glycol monomethyl ether acetate (PGMEA) with side stream sampling from downstream of the capsule to a Rion model KS-19F particle counter. Cumulative levels of particles 30 nm and larger per mL were measured over a 90 min period.

2.3 Defectivity Testing of Wafers Subjected to Filtered Photoresist

Blanket and Patterned defectivity experiments were carried out on 300mm Si wafers in Lithius 300mm (TEL Clean Track) system (Lithius and Clean Track are reg. TM of Tokyo Electron Ltd.) and 193nm ASML Immersion Scanner (1900i). Filter types were subjected to a standard preconditioning prior to use in actual dispense. Test wafers were spun-coated using dispensed ArF immersion photoresist (PR) filtered through test filters (UG2 / XG2) and 45nm L/S patterns were created by exposing photoresist coated wafers with a bright field mask under PSM conditions and developed with 0.263N TMAH developer after post-exposure bake process. Blanket defectivity of photoresist films was measured via KLA-Tencor SP3 system, while 45 mm L/S pattern defectivity was analyzed using the KLA-Tencor 2800 instrument. Defectivity was monitored after 0, 12, 16, and 24 h of photoresist filtration thorough each type of filter.

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3. RESULTS

3.1 Extractables Testing

Figure 3 shows the relative metal levels and organic levels obtained for the 24 h extraction of each filter type, with significantly lower levels observed in both cases for the ultraclean XG2 version versus the standard UG2 version.

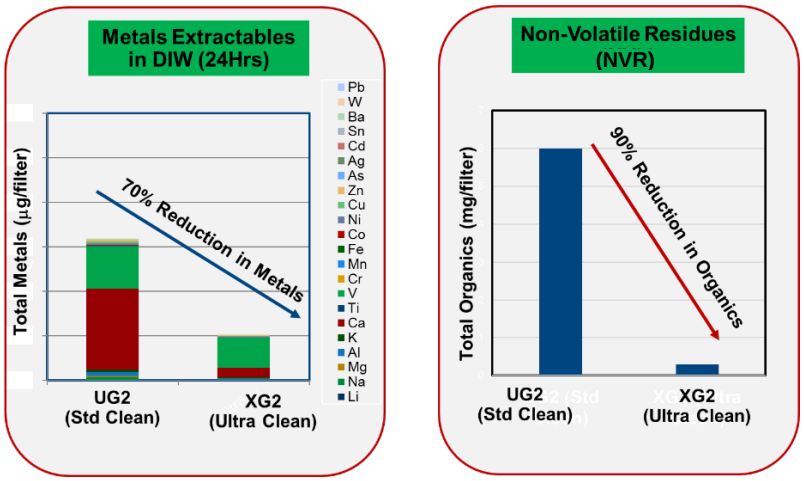

Figure 3. Relative metal and organic extractables levels obtained for UG2 and XG2 filters.

3.2 Particle Rinse-in Testing

Figure 4 provides the particle rinse-in profiles obtained for the two versions of filters tested. It is seen that a stable baseline level of about 10 N/mL is achieved after 20 min for the XG2 version, whereas a stable count level of about 90 N/mL is not achieved until after 40 min for the UG2 version.

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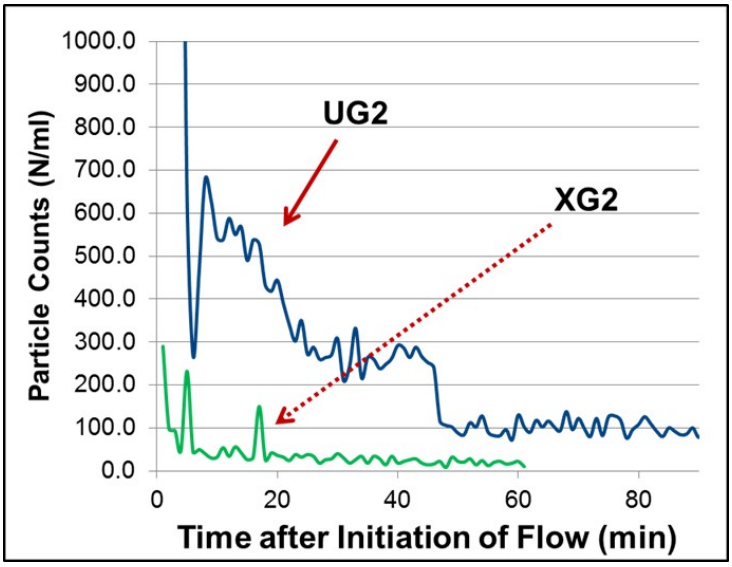

Figure 4. Particle rinse-in curves for particles 30 nm and larger, for capsules subjected to 300 mL/min flow of 70/30 PGME/PGMEA solvent in recirculation.

3.1 Defectivity Testing of Wafers Subjected to Filtered Photoresist

Figure 5 shows relative defectivity levels obtained for blanket wafers subject to dispense of resist from the UG2 and XG2 filters at different times after their installation, along with energy dispersive x-ray (EDX) spectroscopic analysis of specific defects detected. Figure 6 shows a series of 45 nm L/S pattern defectivity maps for wafers subjected to photoresist filtered by the UG2 *vs.* XG2 filter. Figure 7 quantifies the relative defectivity observed for the patterned wafers, along with images showing that the defects detected were primarily of the "bridging" type.

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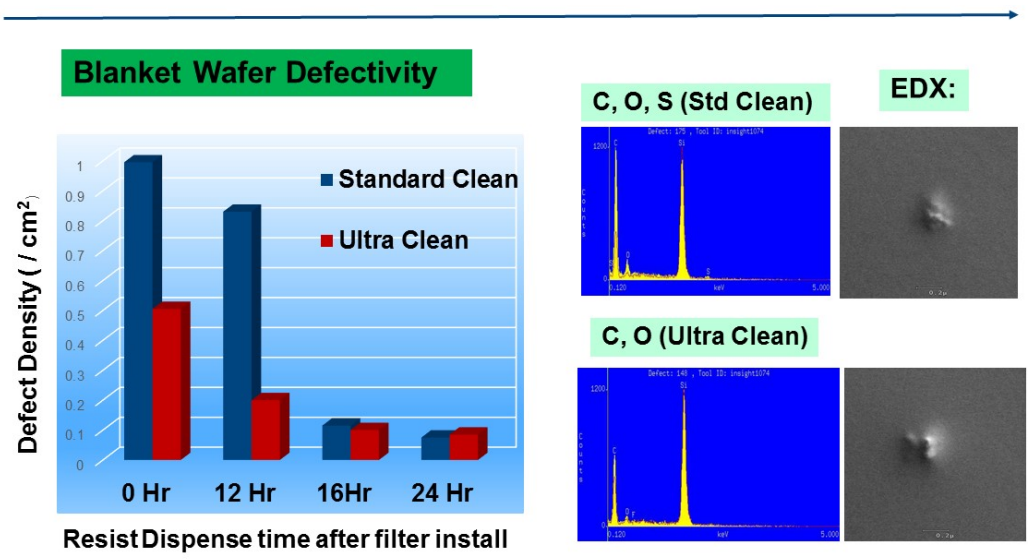

Figure 5. Relative defect density for blanket wafers processed during use of XG2 Ultra Clean filter vs. UG2 Standard Clean filter, with EDX data for defects detected in each case.

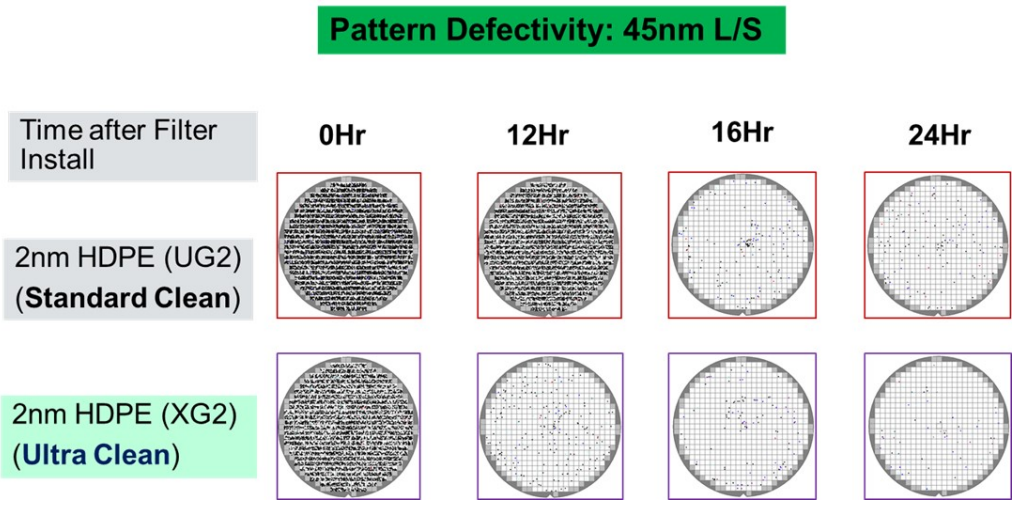

Figure 6. Specific pattern defectivity observed for wafers processed at different duration of use of the XG2 Ultra Clean and UG2 Standard Clean filters in PR filtration.

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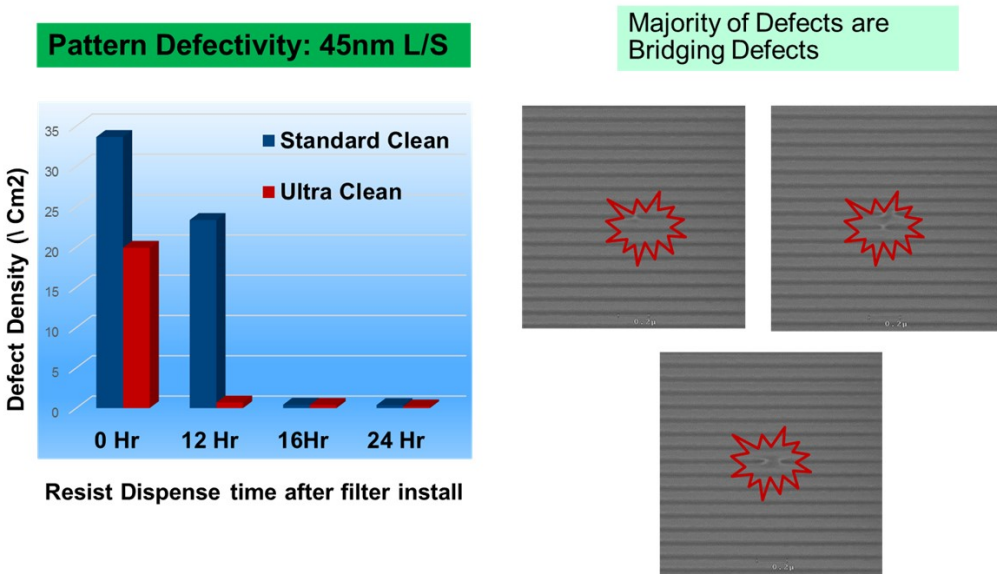

Figure 7. Relative defect density for patterned wafers processed during use of XG2 Ultra Clean filter vs. UG2 Standard Clean filter, with images of bridging defects observed

4. CONCLUSIONS

A study was undertaken to explore the specific importance of initial filter cleanliness as it relates to contamination control and defect reduction in lithography applications. Selected for the work was a 2nm rated filter currently used in lithography applications and available with standard cleaning, UG2, as well as specialized ultra-cleaning, XG2. Samples of the UG2 and XG2 products were evaluated for intrinsic cleanliness in terms of metal and organic extractables and particle release on installation. Subsequently samples of each version were used for POU filtration of PR used in processing of actual wafers, with defectivity measured for blanket and patterned wafers processed at different periods into use of each filter type.

It was found that in terms of intrinsic cleanliness, the XG2 Ultra Clean filter exhibited ta 70% reduction in total metals extractables and a 90% reduction in organic extractables compared to the UG2 Standard Clean filter. In terms of particle rinse-in, a stable baseline particle level, for testing in PGME/PGMEA solvent, was achieved in about 20 min for the XG2 Ultra Clean filter, while achievement of a stable level was achieved after 40 min for the UG2 Standard Clean filter, with the ultimate stable levels of particles 30 nm and larger at about 10 N/mL for the XG2 and 90 N/mL for the UG2. When used in actual POU filtration of 193 nm immersion PR, initial defect levels for both blanket and patterned wafers were found to considerably lower for the XG2 compared to the UG2, with a more rapid decline in defectivity observed over the time the XG2 was in service compared to the UG2.

These results demonstrate that nano-filtration plays in important role in modulating defectivity, with media morphology and pore-size distribution being critical for particle removal performance. But additionally, it is seen that filter cleanliness, capable of being enhanced greatly by improved cleaning processes, has a very significant impact on filter start-up time and bridging defectivity.

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