Microbridge and e-test opens defectivity reduction via improved filtration of photolithography fluids

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ABSTRACT

Reduced tolerance for defectivity is a well-documented consequence of the semiconductor industry's constant progress toward smaller IC device dimensions. Among all manufacturing functional areas, photolithography is arguably the most sensitive to process defects, and thus, strongly influences manufacturing process yield. Microbridging is a well-known type of "killer" defect that can become prevalent in KrF and ArF photoresist systems. When present in BEOL lithography layers, bridge defects can manifest as catastrophic, single-line open circuit faults ("opens") in the metal lines of the finished device. Previous work in BARC + resist systems has demonstrated the effectiveness of improved filtration in reducing bridge defects. The present work evaluates the impact of improved filtration on both litho defectivity and device yield. Application of asymmetric nylon 6,6 filters to a bi-layer resist yielded a significant reduction in microbridge defects via removal of gel-like particle defect precursors. Ultimately, these changes are responsible for two-thirds of baseline defectivity reduction in single-line opens. The same benefits are realized—though via a different mechanism—when all-fluoropolymer filters are introduced for a post-develop rinse, which uses ultrapure water (UPW) that is ozonated to 50ppb. Filtration is applied both to the water point-of-supply and at point-of-use. Over time, a significant reduction in microbridge defects—caused by residual developed resist—was realized for several BEOL KrF litho layers. As with the bi-layer resist process, enhanced filtration contributes significantly (36%) to reduction in the single-line opens defect baseline.

Keywords: Filtration, Nylon 6,6, PTFE, Microbridge defects, Bi-layer resist, Ozonated UPW

1. ENHANCED FILTRATION OF BI-LAYER PHOTORESIST

1.1 Nylon 6,6 filtration materials

It has been proven that finer filtration can reduce defectivity in advanced resist systems.[1] More recently, the comparative effects of membrane pore size, membrane material, and surface modification have been evaluated.[2] Several membrane materials, including nylon, polyethylene, and PTFE, have been developed with finer removal ratings. Nylon, in particular, has shown several attributes that contribute toward reduced defectivity, including a naturally hydrophilic surface that allows for spontaneous wettability and a recurring polar peptide bond (Fig. 1). This polarity bestows upon nylon 6,6 an additional contaminant retention mechanism—adsorption, driven by electrical attraction—that is not present in native HDPE or PTFE. This property enables the adsorption of insoluble resist polymer components, which are instrumental in the formation of microbridge defects within patterned resist (Fig. 2).

One drawback to finer filtration is increased differential pressure (ΔP) across the filter during fluid dispense. This can cause several problems including outgassing of dissolved gases and the formation of bubbles in the dispense line. Increased ΔP can also cause additional stress on the filter and possibly drive the extrusion of "soft" (gel-like) contaminants through filter media. Nylon filters have been constructed with asymmetric pore size distribution (i.e., pore size gradient across membrane depth) in order to overcome this issue (Fig. 3). The open, large-pore upstream structure allows for good exposure of influent to the nylon material with minimal obstruction to flow. The fine-pore downstream structure of the membrane allows for enhanced removal ratings.

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1.2 Application to bi-layer photoresist

The Pall PhotoKleen™ Asymmetric P-Nylon EZD-3 filter assembly (20nm removal rating) was evaluated against an existing 40nm (isotropic) nylon 6,6 product for point-of-use filtration of an ArF bi-layer photoresist system. The enhanced filtration is implemented on a TEL CLEAN TRACK™ ACT™ 8 coater/developer system that is used in litho processing of a 193nm Metal1 litho layer (100nm line/space). An underlayer of 4000Å is applied to the wafer and soft-baked, and then the image layer of 2500Å is applied and baked. The image layer is then patterned and developed, leaving the underlayer unpatterned. The pattern is then transferred through the underlayer by a plasma etch process known as "dry develop". Wafers are then ready for pattern etch into the dielectric substrate below. Finer filtration was initially evaluated only on the image layer for a single litho tool (Dec '07), but was later applied to both the image layers and the underlayers within a group of three tools (Mar '08). Post-litho microbridge defects and single-line opens at e-test are measured in order to quantify the effect of enhanced filtration.

2. ENHANCED FILTRATION OF OZONATED UPW

2.1 PTFE filtration materials

Ozone has been widely used as an effective UPW sanitization agent and for reduction of total oxidizable carbon (TOC). However, while ozone has benefits, it has also been demonstrated that many typical UPW components, including filter materials that offer excellent compatibility with UPW, can suffer oxidation and subsequent material strength and integrity loss in an ozonated system. This degradation may initially be detected as a reduction in or total loss of ozone concentration, due to ozone consumption via material reaction with the ozone. This indicates significant reaction of the ozone on the media or support materials.[3] As a result, proper materials of construction must be carefully chosen for components used in ozonated UPW streams.

Filtration utilizing 40nm and finer membranes has become the widely-adopted standard for many advanced semiconductor process, including lithography. In addition, standard ultra-filtration downstream of reverse osmosis (RO) and at point-of-dispense UPW facilities utilizes extremely fine hollow fiber membranes, rated as tight as 5000 molecular weight cut-off (MWCO). While these advances have enabled production of submicron IC devices, many filtration products are constructed of materials that are not suitable for use even at low ozone concentrations (sub-ppm).

Based upon this knowledge, including previous investigations with filters that employ polypropylene, polyethylene, and polysulfone media, our present efforts focus on the finest PTFE filters designed for high purity chemical applications. The PTFE membrane provides the materials compatibility with ozone while still providing the necessary filtration efficiency. The Pall UltiKleen™ Excellar ER filter—an all-fluoropolymer construction with PTFE membrane—incorporates a hyperfine pore design that provides a significant improvement in the retention of deep submicron size particles. The new PTFE membrane pore structure uses a mixed matrix morphology that layers multiple high and low porosity zones to enhance small particle retention with minimal flow loss despite the fine pore structure.

Additionally, this state-of-the-art PTFE membrane employs advanced surface modification to render the filter less hydrophobic. The intent is that, while the filter still requires to be shipped prewet, it will not dewet under circumstances that would ordinarily dewet a native PTFE membrane. This becomes more critical as the micron rating of a filter membrane is reduced. With increased bubble point of the membrane, wettability becomes more difficult, and the tendency for the filter to dewet in gas-containing chemicals increases. Gas within the fluid can preferentially collect on the pore surfaces, causing blockage of pores and subsequent loss of flow. In addition, gas bubbles can break up and generate microbubbles, which can penetrate into filter effluent and cause resist patterning defects.

Surface modification technologies have been successfully employed to overcome dewetting issues. The Excellar ER filter accomplishes this without liquid chemical treatment, using a proprietary Molecular Surface Tailoring technology to increase the surface energy of engineered PTFE membrane. Unlike conventional coating and grafting methods that may compromise chemical compatibility and purity, the non-dewetting property is achieved by tailoring the surface chemistry on a molecular scale.

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2.2 Cost-benefit considerations

At first glance, the use of an all-fluoropolymer filter seems cost prohibitive in a water system. Specifically, filters composed of alternative materials can cost significantly less. However, the use of alternative materials in an ozonated system includes the risks of contamination due to loss of efficiency or leachables into process fluids, followed by catastrophic failure due to material degradation. To avoid these potential failure modes, an increased change out frequency would be needed. Previous testing within an ozonated UPW supply system shows a filter of polyethylene + polypropylene construction requires a 3-week change-out frequency in order to ensure consistent fluid cleanliness. Conversely, an all-fluoropolymer filter demonstrated consistent performance with no indication of degradation even after 12 months. Theoretically, an all-fluoropolymer filter can be expected to last the life of the tool, barring fouling, making the cost-benefit analysis favorable versus alternative materials. Additionally, a benefit of minimized tool down time can be realized (due to less frequent filter changes).

2.3 Application to ozonated UPW

The Excellar ER filter was installed for post-develop UPW used for several BEOL 248nm litho layers. Source UPW is ozonated to a concentration of 50ppb. Around Dec '07, enhanced filtration was instituted at point-of-supply (downstream of ozone injection) using a 30nm rated product. In May '08, a 20nm rated filter is used to replace the existing product at point-of-use. As with the bi-layer resist evaluation, single-line opens at e-test are measured to quantify the effects of improved filtration products.

3. RESULTS AND DISCUSSION

3.1 Effects on bi-layer resist

A time trend plot of microbridge defect counts is given in Fig. 4. Following the installation of the 20nm asymmetric nylon 6,6 filter for both image layer and under layer (on all three tools evaluated), the average number of Metal1 microbridge defects per wafer drops dramatically (from 2.3 to 0.2). This is attributed to the ability of nylon 6,6 membrane to retain soft, gel-like polymer aggregates that can form within DUV resists and serve as microbridge defect precursors.

Fig. 5 shows a Paynter chart of Metal1 single-line opens defectivity, and quantifies the relative effects of different changes implemented to the resist dispense process. The traces represent defect levels normalized to baseline levels, D0 (Sep '07 = 1.00): Solid circles represent actual measured defect levels, and open circles represent the desired defect level according to a manufacturing improvement roadmap. A portion of output within the months of Nov '07, Feb '08, and Mar '08 contained product lots that were affected by known process excursions, which were characterized conclusively as having no relation to the process changes evaluated in the present work. In the absence of excursions, actual D0 reduction is able to meet goals, with the widest margin of success realized in Apr '08, two months after enhanced filtration is implemented on both bi-layer resist components. The bar graphs quantify the relative impact of individual changes toward the realized D0 reduction (lots with known excursions are not considered). Initially (Dec '07), improved filtration for the resist image layer composes 22% of the D0 reduction. With continued use, the effect of this singular change doubles to 44% in three months. When implemented, enhanced filtration of the resist under layer contributes an additional 22% of the measured D0 reduction. Other process changes were evaluated within the 7-month timeframe considered, but were found to have very small or negligible effects on defect improvement.

3.2 Effects on ozonated UPW

A Paynter chart of MetalX single-line opens is given as Fig. 6. As with Fig. 5, the process defect baseline, D0, is normalized to the start of the evaluation period (Sep '07 = 1.00). Over the 12-month evaluation period, the process changes implemented are able to drive D0 down (solid circles) at a rate that is almost sufficient to match targeted performance (open circles). Enhanced filtration at point-of-supply initially comprises 11% of D0 reduction. With continued use, the contribution increases to a steady 20%. Improved filtration at point-of-use initially contributes 6% to D0 reduction, but within two months, the effect increases to 16%. Fig. 6 also contains several other simultaneously implemented process changes; however, enhanced point-of-source and point-of-use filtration are clearly the greatest contributors to reduced D0.

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3.2.1 Filter rinse-up considerations

Source UPW feeding the coater/developer tool has undergone long-term continuous ozonation, which has caused higher particle counts over time (vs. tools using non-ozonated UPW). Following installation of the filter, particle counts did not drop quickly as initially expected. This was attributed to the presence of bubbles (i.e., artificial particle counts) due to the very fine membrane pore structure and the gas generating capability of ozone. Effluent particle levels were monitored using a laser particle counter (PMS Ultra DI50). After sufficiently rinsing, filters were able to achieve a base line of less than 0.6 N/mL (∑: ≥0.05µm).

4. CONCLUSIONS

It was demonstrated that enhanced filtration of bi-layer resist and post-develop ozonated UPW contribute significantly to reduction in post-litho microbridge defects, and ultimately, to a significant reduction in single-line opens at e-test. In bi-layer resist, an asymmetric nylon 6,6 product provided improved filtration of soft, gel-like contaminants that function as microbridge defect precursors. Polarity of the membrane surface provides a mechanism for retaining these contaminants (electrostatic adsorption) that goes beyond traditional filtration mechanisms (e.g., direct interception). Moreover, the asymmetric pore size gradient enables a finer filtration rating (20nm vs. 40nm) while eliminating the expected increase in flow ΔP. When applied to both resist image layer and underlayer, improved filtration drives a ten-fold decrease in microbridge defects, and accounts for two-thirds of the realized reduction in single-line opens D0.

Enhanced filtration products built around surface-modified, non-dewetting PTFE membrane are used in 50ppb ozonated UPW at both point-of-source and point-of-use. Improved cleanliness of post-develop rinse water leads to improved elimination of developed resist residue, which can also cause microbridge defects. The all-fluoropolymer filters demonstrated excellent chemical compatibility over 12 months of service use, and comprised an estimated 36% of single-line opens D0 reduction.

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FIGURES

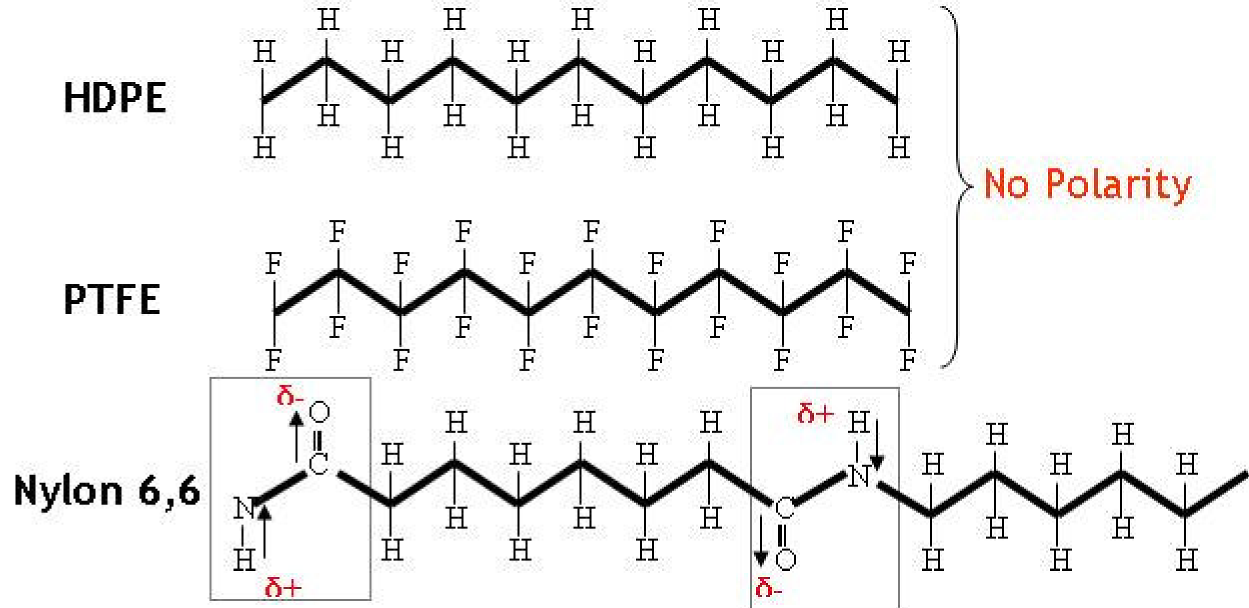

Fig. 1. Bond-line representation of chemical structures for various filter membrane materials. Partial positive (δ+) and partial negative (δ-) charges due to electron delocalization in nylon 6,6 peptide bonds are emphasized.

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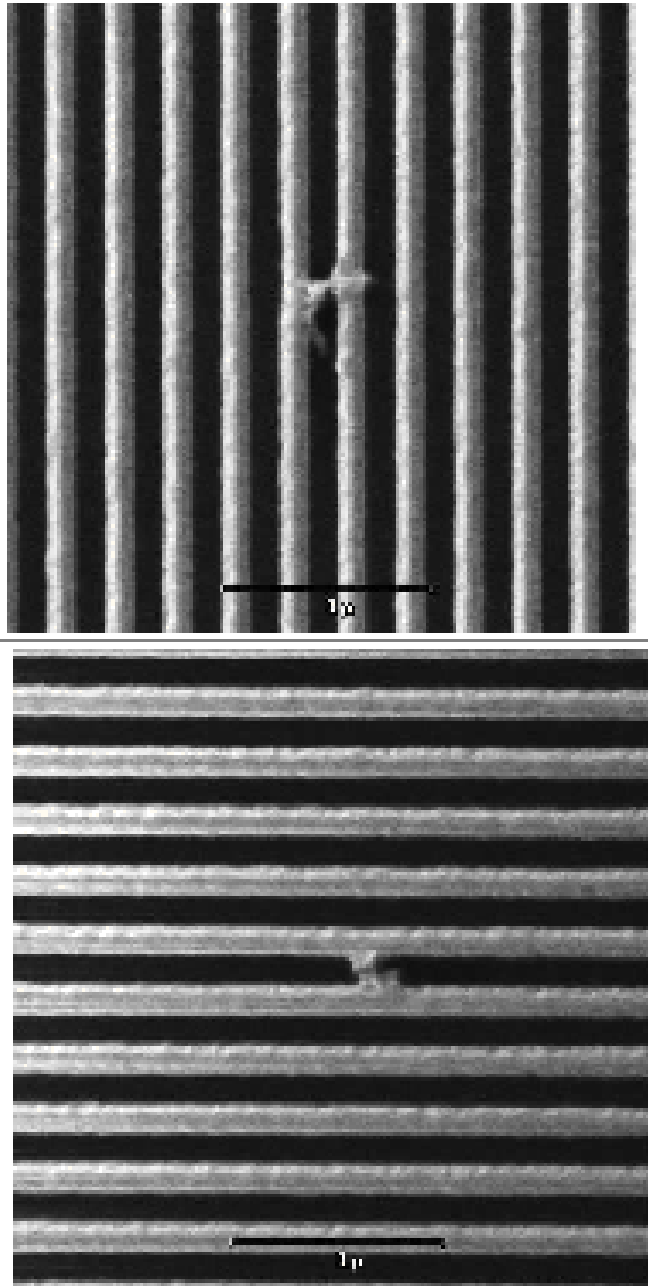

Fig. 2. SEM images of microbridge defect. Black scale bar is 1μm.

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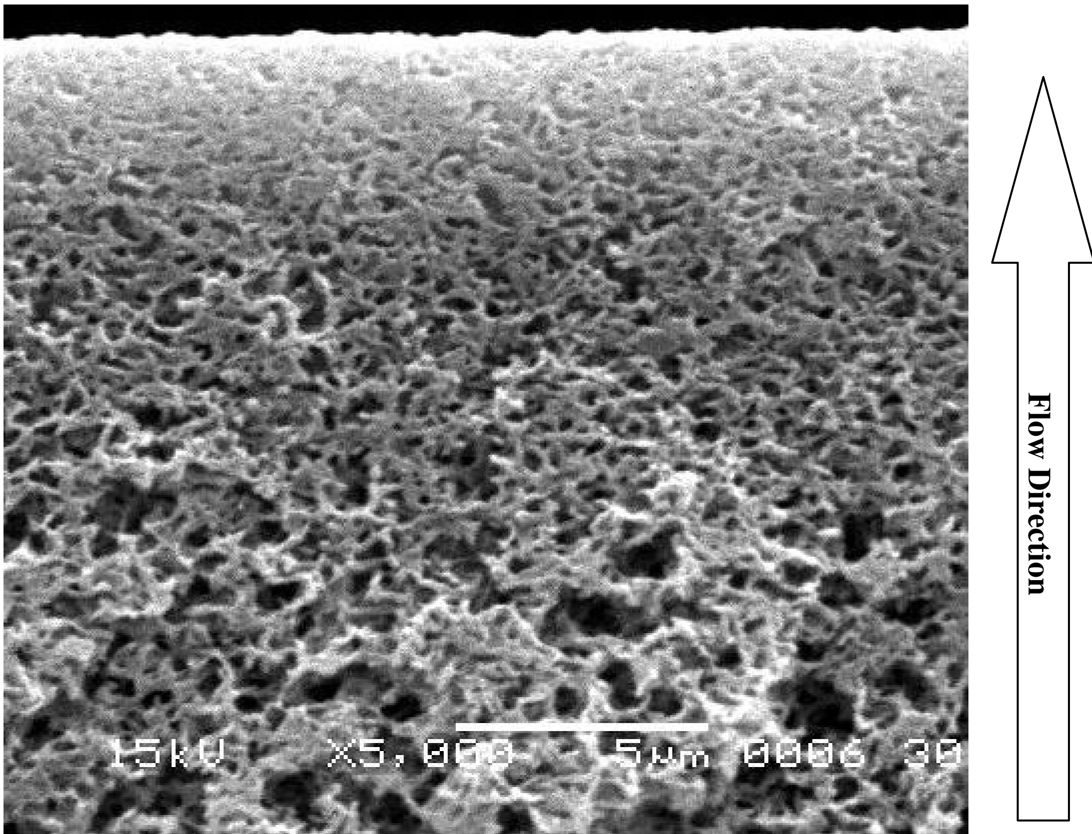

Fig. 3. Cross-sectional SEM image of asymmetric nylon 6,6 membrane. Larger pores are at the bottom, fine pores are at the top.

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Fig. 4. Time trend chart of Metal1 post-litho microbridge defects. Vertical dashed line indicates point of enhanced filtration implementation of resist image layer and underlayer. Each data point represents one wafer.

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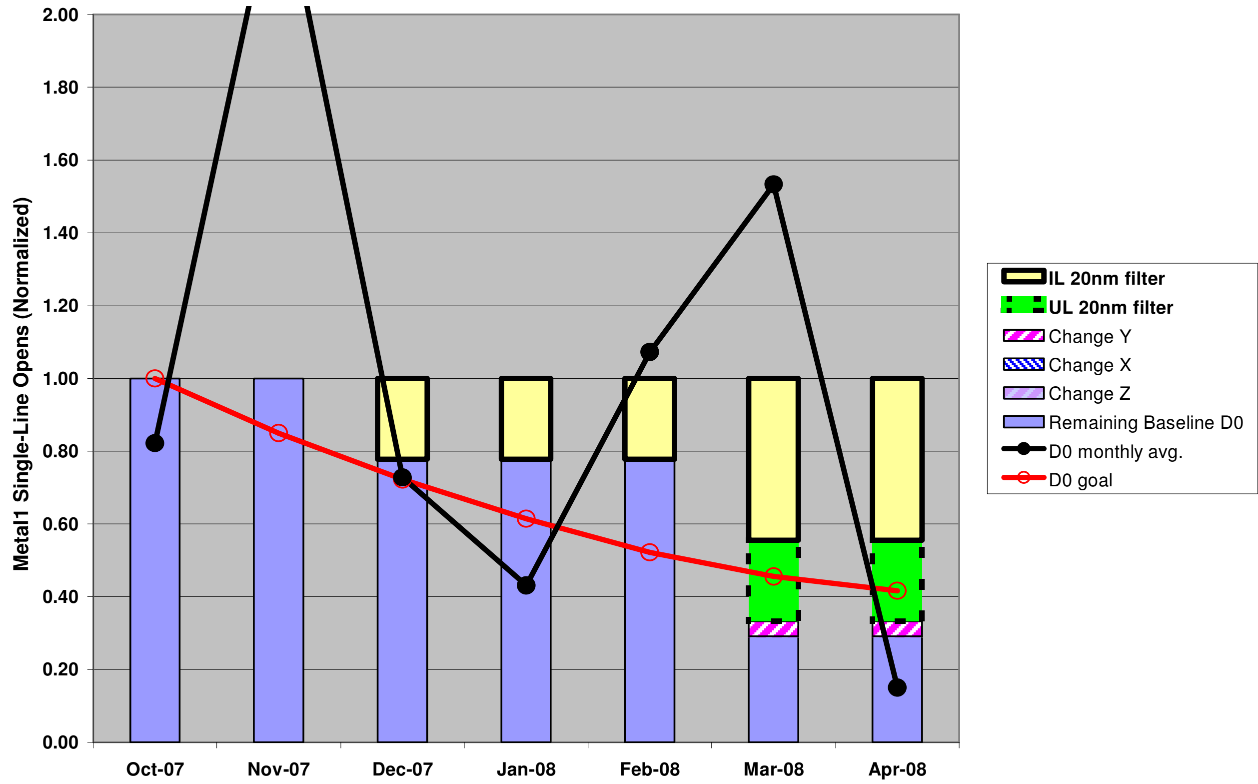

Fig. 5. Paynter chart of Metal1 single-line opens defectivity, and the relative effects of changes to bi-layer resist dispense.

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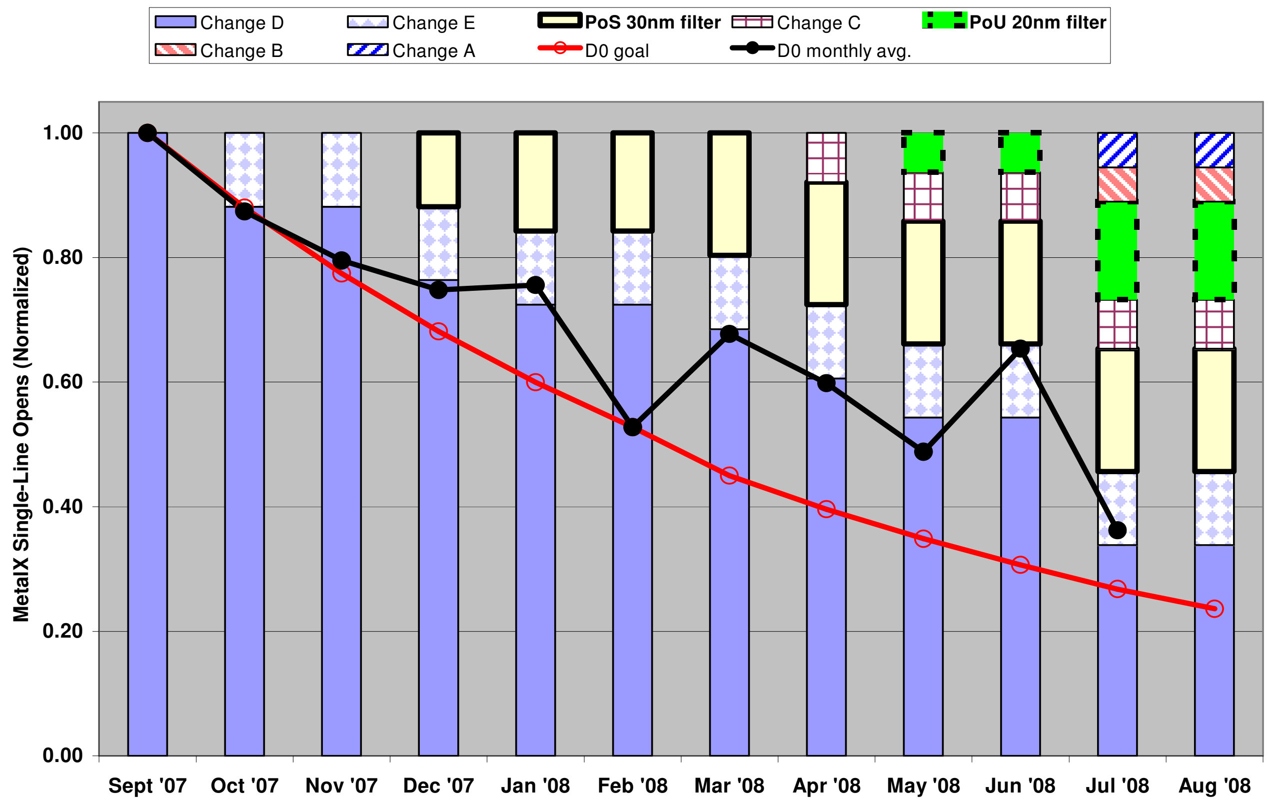

Fig. 6. Paynter chart of MetalX single-line opens defectivity, and the relative effects of changes to the post-develop ozonated UPW process.

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