Strategy for Yield Improvement with Sub-10 nm Photochemical Filtration*

J. Braggin – Entegris; C. Brodsky, M. Linnane, P. Klymko – IBM Microelectronics

ABSTRACT

Process and equipment engineers are always seeking ways to improve yield quickly and efficiently, especially on newly developing processes. These engineers have many tools at their disposal – equipment enhancements, software upgrades, and materials improvements. Many of these tools come from other equipment suppliers (OEMs) and materials suppliers who all benefit from close collaboration with IDMs to improve yield.

This paper discusses strategies utilized to improve yield on 32 nm back end of line (BEOL) lithography processes with sub-10 nm photochemical filtration. This collaboration generated electrical yield data that validated the performance of several sub-10 nm photochemical filters on various resist and ancillary chemicals used in a tri-layer stack. Examples of yield enhancement include: the use of 5 nm ultra-high molecular weight polyethylene (UPE) in optical planarizing layers (OPL) that showed a 69% improvement in overall median yield for an OPL material used in the first metallization layer, and a 26% improvement for a second OPL material used in subsequent metallization processes. In addition, this paper presents data studying prewetting of a 5 nm point-of-use filter before track installation. Building on the success of this collaboration, an example filtration roadmap is also explored to show the benefits of using advanced filtration in 32 nm technologies and beyond.

INTRODUCTION

In recent years, close supplier collaboration has become a critical factor for success in advanced semiconductor technologies. Benefits of successful collaboration include: sharing the escalating costs of research and development, shared learning, and the ability to leverage synergistic engineering resources.[1] As increasingly complex technology advances create even greater barriers to rapidly increase yield, it is imperative for IDMs, OEMs, and materials suppliers to collaborate to solve problems.

Continued extension of 193 nm optical lithography has made this collaborative model particularly important. Changes from dry to immersion lithography and single- to double- to triple-patterning have all created manufacturing complexities that pose significant, but surmountable challenges with strong advances from materials and tool suppliers. For example, photochemical suppliers in particular have been able to support advances in high-NA imaging with the introduction of multilayer patterning stacks and ancillary chemicals that aid in lithographic processing. However, by adding additional films, the IDM is taking a risk that they are adding increased defect density with every additional process step.

To address defect densities directly related to photochemical use, several studies have been conducted[2,3,4] to understand the impact on defectivity with changes to photochemical point-of-use filters. Many of these studies focused on post-develop defectivity as measured by inline defect metrology equipment. Of highest interest was the microbridge, or single-line open defect. This particular defect has become increasingly challenging to eliminate since the introduction of 45 nm processing. Examples of the microbridging defect in a 32 nm dense line space pattern are seen in Figure 1.

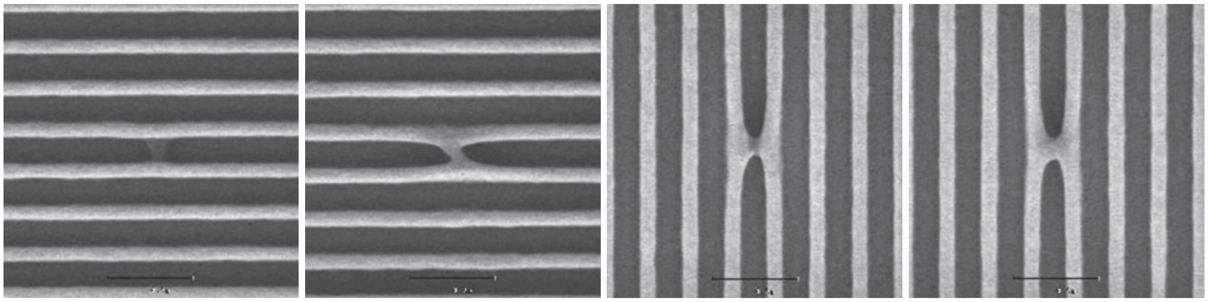

Figure 1. Single microbridging defects that create single line open failures in BEOL patterning.

While these defects can be captured by traditional inline defect metrology tools, the capture rate does not often reflect the actual impact on electrical yield. In addition, these methods only indicate a defect that has been created after several layers of coating and development, and cannot determine the direct root cause of the defect, particularly in multilayer sacrificial masking steps. Therefore, new methods have been incorporated into yield learning cycles to be able to identify these defects with higher capture rates, and drive more effective learning cycles towards eliminating them.

One such approach is to utilize full-field electrical test learning vehicles that provide more depth of insight over typical kerf monitors. For example, PDF Solutions has created Characterization Vehicles®[5] that are designed to mimic pattern densities on critical levels, provide single-level test capability, and in-depth discrimination of defect densities and size distributions even within a single exposure die.

This type of evaluation is particularly well suited to running point-of-use filter experiments on pattern transfer layers, such as those found in a tri-layer stack. By running a single material through different point-of-use filters and then measuring the resulting electrical yield, the effect of filtration on particular stack layers can be examined quickly and effectively. On the other hand, reliance on optical defect metrology raises serious questions regarding detectability and capture rate when dealing with films that are utilized as etch transfer layers. Inspection at lithography is well established, but stopping mid-stream in an etch transfer step is often impractical due to surface roughening of sacrificial transfer layers compromising the optical inspection signal. Electrical test eliminates these questions and provides an absolute certainty in the results.

The results presented in this paper denote the importance of point-of-use filtration of the various tri-layer materials as a means to improve electrical yield in 32 nm BEOL lithography processes. The results, however, are not limited to this technology and will extend further into the next technology nodes. In addition, these results can also be expanded to photochemical materials suppliers who can utilize similar filtration technologies during manufacture to improve their products.

EXPERIMENTAL

Tri-layer Stack

IBM's BEOL tri-layer stack consists of four spin-cast layers, as seen in Figure 2. The layers are the OPL, a spin-on silicon (Si) hard mask, the photoresist, and the topcoat. Before each layer is applied, a prewet solvent is dispensed to reduce the amount of chemistry needed for each layer. Multilayer patterning stacks such as this, while enabling greatly improved imaging capability, presents several opportunities for the inclusion of defects. For example, in the case of spin-on layers, there is the threat of defectivity in the materials and coating process, starting with each prewet step.

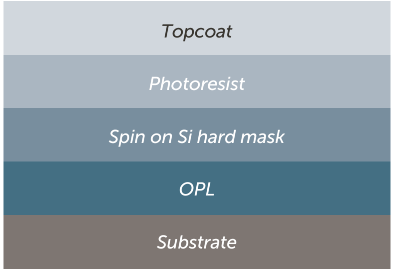

Figure 2. Tri-layer stack.

After the four layers are spin cast, only the top two are developed before dry etching. Therefore, if defects are present in the bottom two layers they will not be revealed until after dry etching and further wet stripping.[1]

Process Equipment

All experiments were performed on the Tokyo Electron Limited Clean Track Lithius i+® coupled to an ASML™ TWINSCAN™ XT: 1900i scanner.

Rapid Yield Learning Vehicle

To fully explore the defectivity results as a measure of yield, PDF Solutions Characterization Vehicles were used at thin wire metal levels to determine yield improvements based on point-of-use filtration changes. A minimum of 36 wafers were analyzed for each experiment. The primary defect of interest identified by the characterization vehicle was single line opens.

Point-of-Use Filtration

Point-of-use filters used for these experiments were all Entegris Impact® 2 V2 filters with varying pore sizes. All UPE filters tested below the 10 nm retention rating use an asymmetric morphology, where the average pore size decreases as a fluid moves across the membrane. This is represented by Figure 3. Asymmetric membrane morphologies allow for high flow rates while maintaining challenging retention ratings.

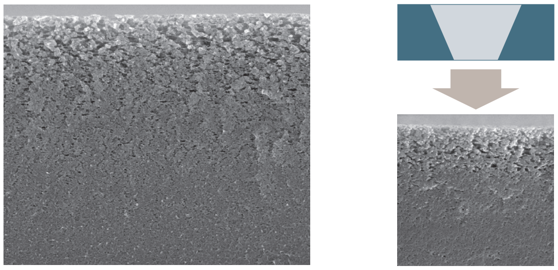

Figure 3. Left: Asymmetric membrane structure; Right: Cartoon of an asymmetric filter membrane with SEM micrograph of an asymmetric membrane.

Experimental Procedure

For each tri-layer stack material studied, two different point-of-use filters were compared. The material of interest was installed on a production Tokyo Electron Limited Clean Track Lithius i+ configured with two independent dispense points for a given photochemical. Each dispense point was equipped with a particular filter of interest. Specific wafers were then alternated through these two dispense points within a single parallel integrated track flow to help block against many sources of extraneous variation that may impact microbridging defects. This methodology helped ensure a strong signal-to-noise ratio to determine if the point-of-use filter had a statistically significant effect on yield. A similar methodology was utilized for prewet solvent, comparing a line using a Protego® Plus purifier and other lines not using this purifier, running in parallel in a single integrated track flow.

RESULTS AND DISCUSSION

The following results presented represent electrical yield defectivity results as determined by PDF Solutions Characterization Vehicles.

OPL: Experiment 1

The OPL layer in the tri-layer mask aids in high-NA imaging performance, and in many cases, can also facilitate improved etch dimensional capability. While this material is not directly imaged, defects present in the material can directly affect the yield if defects in the layer are transferred during etch.

In one particular experiment, a specific OPL (OPL A) was split between a 20 nm symmetric UPE Impact 2 V2 filter and a 5 nm asymmetric UPE Impact 2 V2 filter. Results from this experiment are shown in Figure 4.

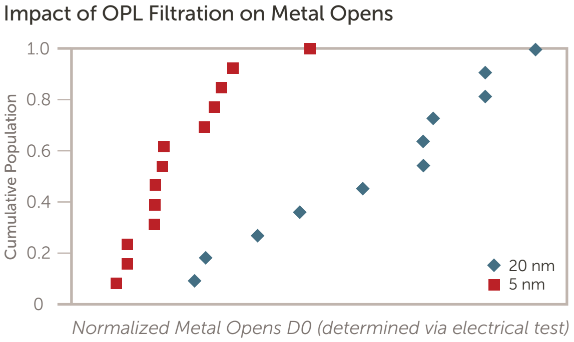

Figure 4. OPL A electrical defect density improvement from 20 nm UPE filtration to 5 nm UPE filtration.

Three split lots demonstrated a median 69% reduction in electrical yield failures when changing from a 20 nm UPE filter to a 5 nm UPE filter. The benefit was demonstrated across two different manufacturing lots of the OPL material, one of which had shown significantly higher defect levels before processing.

Likely these materials had small contaminants that were transferred into the substrate materials post-etch that would not have been caught by traditional inspection techniques. Rapid electrical yield learning was the only way to show the yield improvement for this particular layer in the tri-layer stack.

OPL: Experiment 2

In a similar experiment, another OPL material (OPL B) was tested utilizing the same filter combination. Results are seen in Figure 5.

OPL B Experiment

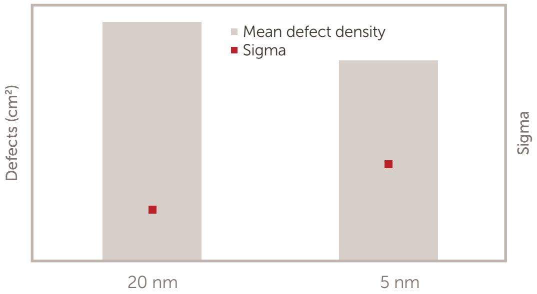

Figure 5. OPL B electrical defect density improvement from 20 nm UPE filtration to 5 nm UPE filtration.

OPL B showed a 26% reduction in median defect density across 3 development lots, including multiple thin wire levels.

Both OPL layers showed a significant yield improvement when the point-of-use filter was changed. Likely these materials had small contaminants that were transferred into the substrate materials post-etch that would not have been caught by traditional inspection techniques. Rapid electrical yield learning was the only way to show the yield improvement for this particular layer in the tri-layer stack.

Topcoat evaluation

Topcoat defectivity has also challenged IDMs since the introduction of immersion lithography. As such, several studies have been conducted to optimize topcoat defectivity or completely remove it from the stack. In this experiment, the topcoat material for the M1 level had been creating a significant amount of defects. Initially a 5 nm asymmetric UPE filter was installed on the top coat material. While this particular filter improved performance, further reduction in defectivity was required. At first a 3 nm asymmetric UPE filter was installed to try to improve performance. No statistically significant performance improvements were seen with this change.

Another method studied in hopes of reducing defectivity and improving the filter qualification time was trying a preliminary prewet of the filter membrane before installation. Methyl Isobutyl Carbinol (MIBC) was considered as a potential prewet solvent for 5 nm point-of-use filters. Figures 6 and 7 below show the relative electrical defect densities and inline defect metrology defect densities when comparing filters that were installed dry or installed with an MIBC prewet. In this particular case, the prewet did not effectively reduce defectivity, and in fact was detrimental.

Introducing a prewet solvent to a filter membrane can improve start-up time by wetting the membrane ahead of the introduction of the primary imaging chemistry. However, the introduction of another chemistry can potentially be detrimental if the chemistry is not matched to the primary imaging chemistry. In addition, today's solvents may include impurities, such as metallic ions, that could increase defectivity.[6] It is becoming increasingly important to understand the purity requirements of solvents before use in lithography applications.

Topcoat Experiment: Filter Prewet

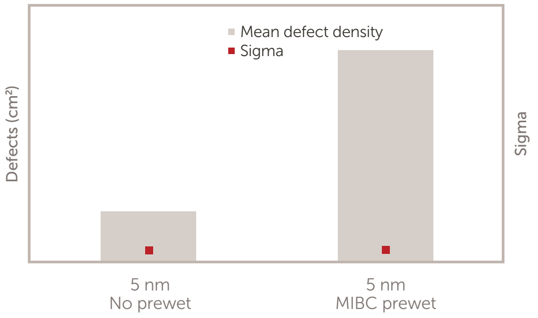

Figure 6. Comparison of electrical yield response to filters with and without prewet.

Topcoat Experiment: Filter Prewet Inline Defect Data for Single Line Microbridging

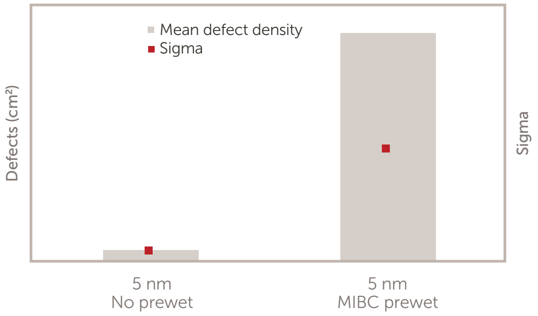

Figure 7. Inline Defect Data comparing prewet of 5 nm asymmetric UPE filters for top coat materials.

CONCLUSION

This set of experiments concretely proved that point-of-use filtration in the lithography sector can have a statistically significant impact on electrical yield, especially for the smallest yield detracting defects. In addition, the studies showed that filtration of all materials in a 32 nm tri-layer stack, not just the photoresist, can be improved with sub-10 nm filtration. While the data presented was limited to 5 nm pore sizes, even smaller pore sizes were tested using these methodologies and were found to have no negative impact on electrical yield. Therefore, point-of-use filtration has not yet reached the point where the retention rating is detrimental to the imaging and defectivity performance of leading-edge lithography materials.

As such, it is anticipated that as IDMs drive 22 nm and beyond technologies, additional advanced filtration technologies will be required to improve yield in the lithography sector. The 32 nm data presented can be used as an initial measure of performance that can be directly transferred to leading edge processes as they are being developed and improved. Existing processes that are reapplied to next generation technologies can also benefit from improved filtration to meet D0 defect density scaling requirements. A filtration roadmap thus becomes an essential part of the overall defectivity strategy for migration to more aggressive technology ground rules.

While this paper explored the improvement yield based on point-of-use filtration, the leanings are not limited to end users of lithographic materials. These results can be further translated upstream to photochemical materials suppliers. Today, materials suppliers are being challenged to provide the cleanest materials to IDMs. The filters in this study can also be adopted by the photochemical manufacturing process, whereby the materials can be filtered by the sub-10 nm filters before packaging and shipment to IDMs. By improving the material at the source of manufacture, it is likely that fewer defects will translate from the bottle to the wafer, helping to improve the time to yield. This approach will also lessen the burden on point-of-use filtration as a primary means of defect control.

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