Improving Tool Efficiency through Automated Process Window Qualification

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Abstract - **It is widely understood that a close attention to systematic defect issue is required to succeed in a device development and production of 45 nm and beyond. For 45 nm, use of OPC created tremendous challenges in both optimization and validation of proper amount of optical correction needed[1]. OPC treatment and variation across wafer have to be controlled and monitored with utmost care where there can be issues near the edge of wafer or under process variations. Generally for 32 nm and beyond, Semiconductor industry's adoption of Immersion and Double Patterning Lithography (DPL) are bringing new challenges in controlling process for best yield. DPL sites can introduce patterning and overlay issues. To introduce a new process or device, Lithography process window must be well understood for faster process development and to prevent catastrophic yield loss. CD and overlay variations must be measured at the most appropriate sites across die and wafer to fully characterize a process.**

Today Lithography engineers are utilizing various approaches in understanding the process window including CD metrology and Defect inspection using wafers where Focus and Exposure conditions are modulated. Layout and ranges of conditions may vary based on devices and technology. Generally CD metrology provides good sensitivity to the process variation but it is often limited by ability to sample across wafer. Defect inspection provides much wider coverage but requires engineering resources for separating real pattern failure from particles or other pattern noise. In the past Litho process window qualification has been performed requiring much of manual intervention by users.

In this paper, we introduce a new technique that enables automatic process window qualification that reduces user intervention while making the procedure repeatable among different users.

I. INTRODUCTION

Goal of the new technique is to improve upon existing Process Window Qualification technique, often referred as PWQ, by increasing the quality and consistency of the results and reducing resources required to execute the analysis through an automated method. Main advantages of the new technique are:

1) Reduced inspection and review tool usage where data collection can be done automatically. As a result, overall time-to-result is improved.
2) Standardized approach to data collection, easily adaptable solution to existing environment, use of special algorithm so that quality of result is consistent regardless of users once a standard method is deployed.
3) Generation of Bossung images where a progression of particular pattern can be visualized across Focus and Exposure modulation even if defect is not detected at lower modulation conditions. The images can be shared over WEB using HTML formatted files.
4) Use of Design Layout information to identify pattern failure types and to group them according to the similarities.

II. FLOW OF ANALYSIS & TIME SAVING

PWQ has been adopted as a proven technique to qualify the process window of a given design. This technique requires a specialized wafer with special set up requirements that has been demonstrated in both Bright Field and Dark Field inspection technologies[2]. Inspection of the wafer requires much effort and time to maximize identification of all key pattern failures. The efforts include setting up special inspection recipe or recipes to optimize the defect detection sensitivity and careful manual SEM review of defects to discern Litho related pattern failures from random pattern and particle defects. Aside from the inspection sensitivity, qualification of the results hinges upon the amount of user's time, effort, and expertise. If a user spends more time reviewing additional defects at the SEM, a larger amount of pattern types can be discovered. An experienced user also may be able to zoom into the more relevant Focus-Exposure modulation conditions and therefore find more critical patterns compared to a novice looking for defects at random locations. With high defect count on a given PWQ wafer, often >500k, a random selection of defects may result in missing important systematic and pattern defects. Such disparity in effort and expertise makes it challenging to achieve repeatable quality results on an on-going basis. To achieve a quality and repeatable result, it requires a dedicated engineer to evaluate

all PWQ wafers so that each analysis is well controlled and consistent results are delivered. However it is not efficient for one individual to analyze all PWQ wafers as the need for the analysis may arise any time of the day or week. For production worthiness, multiple users should be able to analyze the wafers. More over, subjectivity is a major concern in analyzing a PWQ result when multiple individuals are analyzing the wafer. On a given wafer, there may be number of different pattern types that are failing at various modulated conditions. Since defect count is typically high, an engineer has to visually determine where to review to define process window boundaries while sampling a finite number of defects on SEM. This subjective approach introduces variability among different users, not to mention prolonged time in analyzing the inspection results. With manual approach of defect selection and sampling, it is virtually impossible to obtain a repeatable and quality analysis when there is a time constraint. Using the new approach which includes automated defect prioritization and sampling, overall time spent on inspection and analysis is significantly reduced while the data collection is systematically executed (Fig. 1). The time saving results from automated set-up to automated SEM image collection where in the manual approach, a user has to spend many hours sitting in front of SEM review tool collecting images at user discretion. With the new approach, SEM images are automatically collected and a user can review the defect images off-line to determine process window by defining shots that show failed patterns such as bridging or line shorts. In this new approach, the number of defects reported post-inspection can be reduced for a given reticle shot in the event a defect count is extraordinarily high (Defect count can be high either due to nuisance or high defectivity at extreme modulations). Reticle shots with extremely high defect density can be processed through an automated filtering (Down-Sampling) to reduce the count while maintaining the types pareto constant. Such technique keeps the extreme modulated die at manageable defect count while at the same time preserving defects for reticle shots with relatively low counts. With the automated defect reduction and automated sampling of defects based on proprietary sampling techniques, total time required to analyze the wafer is reduced by 40%. With the new approach, an experienced user can set up the process of analyzing PWQ and apply the same methodology in a production environment or through multiple Fabs. Such approach not only reduces variability among users but it standardizes the method of analysis so that the quality of result is independent of how much effort is exerted in performing the analysis. Such standardization can increase productivity and quality of analysis for Fab by enabling consistent approach in process window qualification.

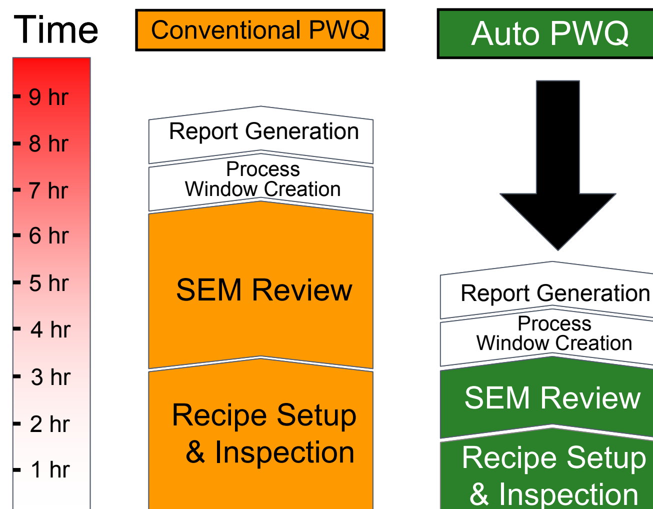

Fig. 1: conventional approach consists of much manual efforts in data collection that results in higher total overall time.

III. AUTOMATED SAMPLING

A key enabler that allows the consistency is the use of systematic approach in sampling the right defects to review. Automated sampling and data collection consists of several components that include binning by pattern and prioritization of defects within bins. When each defect is binned based on their pattern background (details explained in section V of this document), the bins are prioritized according to the likelihood that the pattern is a Litho related failure. For example a Litho pattern failure bin would track the level of modulation where a random pattern failure would have no correlation to modulation conditions. A Litho related pattern would have tendency to fail more at higher modulated conditions. Once the bins are prioritized, a predefined number of bins can be used to determine the bin sampling to enable sampling from systematic pattern types. For sampling defects within the selected bins, defect prioritization is use to identify defects with highest score. These scores are then used to determine which defect to sample for SEM review. Such technique systematically determines which defects to sample so that it eliminates variability among different users. In implementing sampling strategy, several parameters need to be determined. A total number of sampling budget and number of bins need to be determined (Fig 2A). Based on the sampling budget, defects can be selected at either linear fashion among the different modulated shots, or a biasing can be used to sample additional defects in the FE modulated conditions that are closer to the estimated process window. Such biasing can be controlled by using the Modulation selector and executed as part of inspection recipe so that a consistent method is used for every wafer. In some cases there may exist pattern failures that are undetected by the inspection system due to subtle nature of the pattern failure. For this type of defect, a concept of ‘ghost’ defect is used. Ghost defect is a virtual defect

(location) that can be created based on detected defects. Once the ghost defects are generated, they can be used to sample among modulated shots that are close to nominal condition or the ghost defects can be used to create Bossung image where a panorama of particular pattern can be visualized throughout the low to high modulation conditions. Such technique of ghost defect generation is illustrated in Fig 2B.

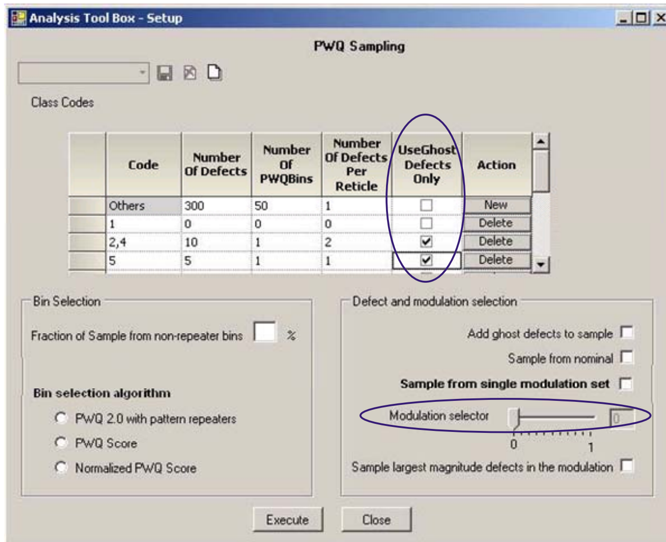

Fig. 2A: Sampling budget and maximum bin can be defined to generate SEM review data. Sampling can also be biased towards critical region.

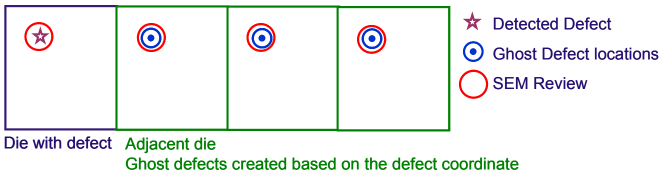

Fig. 2B: Virtual defects are created to enable review of potential failures using SEM even if the defect is not detected by inspection.

IV. REPORT GENERATION

Once the automated sampling and SEM image collections are completed, a user can now review the saved images off-line to identify modulated conditions where patterns start to fail. Based on the data review, a user can define a process window and generate a report (Fig. 3A). In the document, a sample wafer that was used to compare manual method and the new approach is shown. This study confirmed the reduced efforts (time and user intervention) required by the new approach. Results show that the process window determined by the two methods matched or are very similar (Fig. 3B) based on SEM verification of the results. There was a small discrepancy that seems to be due to defect selection (which can vary from run to run, especially in the case of manual approach). For this case study Bright Field inspector usage time was reduced with the new methodology by 50%. It also concluded that the sampling is more efficient with the new methodology. SEM tool usage time was reduced and more automated with the new methodology where the total SEM usage time was reduced by 66%. Not having to sit in front of SEM review tool also frees up engineering time. Once the process window is determined by reviewing the collected defect images, HTML output for IBM employees to view using an Internet Browser (Fig. 3C). By capturing Bossung images, pattern variation across modulation can be easily visualized for anyone needing to understand the behavior or pattern across the Litho conditions. While the current report shows relatively simple contents, enhancement of reporting capability is anticipated to fully take advantage of the automation either through HTML or other software medium.

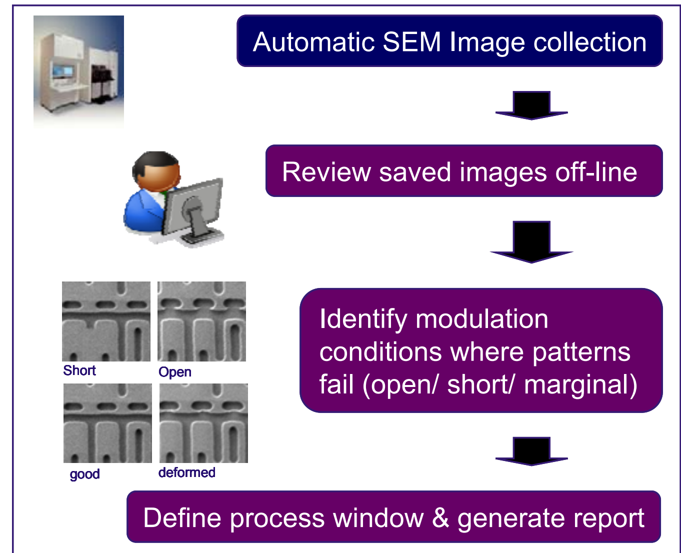

Fig. 3A: After the automatic SEM image data collection, user needs to review the data to determine process window and generate report.

Manual	-1.4mJ	-0.70mJ	POR	0.7mJ	1.4mJ
0.075um					
0.05um					
0.025um					
POR					
-0.025um					
-0.05um					
-0.075um					

Auto	-1.4mJ	-0.70mJ	POR	0.7mJ	1.4mJ
0.075um					
0.05um					
0.025um					
POR					
-0.025um					
-0.05um					
-0.075um					

Fig. 3B: Process windows determined by the two methods show comparable results. The map on the left is using manual method and the map on the right using automated approach.

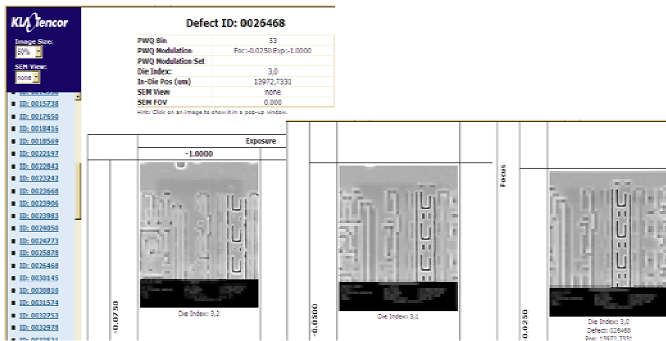

Fig. 3C: A sample of automated WEB-based report showing pattern variation across different focus condition.

V. GROUPING BY DESIGN LAYOUT PATTERN

In the past, PWQ wafer was inspected and analyzed based on inspection attributes only. Defects were often grouped by the images taken from defect inspection or by repeating behavior among shots, but such technique has limitation for ever decreasing feature sizes where pattern fidelity is challenging and occurrence of pattern failures are not repeating by locations within the reticles. With the new approach each defects are binned according to the layout pattern where the locations that defects exist (Fig. 4). The technique of grouping by design layout has been well established and documented[3&4]. By binning based on the design layout pattern, the grouping behavior no longer depends on the pattern fidelity of the inspection patch image. Once the defects are grouped according to the layout, the defects are prioritized for sampling as described in the earlier part of this document.

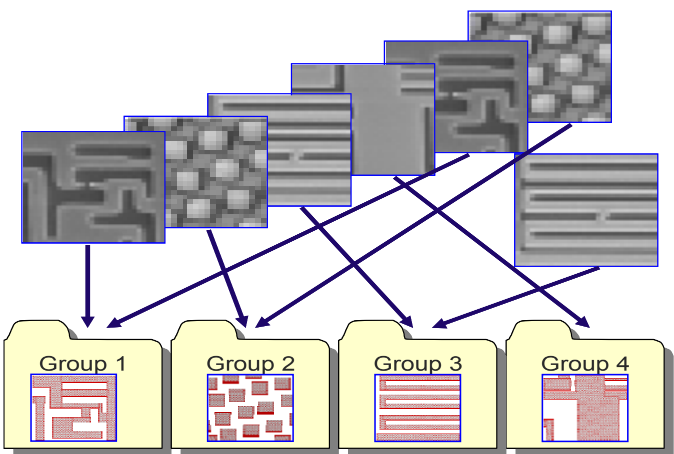

Fig. 4: Defects detected on PWQ wafer are binned based on Layout pattern. Such technique creates automatic grouping of failures that occur on same pattern types.

VI. SUMMARY

Identification and verification of process window is a challenging task for 45 nm and beyond technology nodes. Introduction of new Lithography enablers such as OPC, Immersion and DPL brought new challenges Semiconductor industry must face. In this paper a new approach was demonstrated to 1) reduce time to tool usage time for both inspection and review systems, 2) standardize the analysis technique to reduce user-to-user variation, 3) automatically generate Bossung images for data consumers within the company, 4) utilize design layout to group defects for better binning and sampling for SEM review. This new automated approach promises to be one of the key enablers for new technology nodes going forward.

VII. ACKNOWLEDGMENT

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