Novel Technique to Separate Systematic and Random Defects During 65nm and 45nm Process Development

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Introduction

Defect inspections performed during process development often result in 10^5 to 10^6 defect counts on a single wafer. Such defect data include both systematic and random defects, only some of which may be yield-limiting. The traditional method of reviewing a random sample of only 50 to 100 defects on the SEM makes it difficult to identify important systematic defects from a defect wafer map.

This paper describes a powerful new method to discover and separate systematic defects within a large defect sample, prior to SEM review. By integrating design data with defect data, this method enabled us, for the first time, to accurately bin randomly distributed structural systematic defects using the design background.

Instead of relying on inefficient random review sampling to identify defects of interest (DOI), our technique applied a pattern search engine accessing the design files to correlate the DOI to its pattern background. It was able to group defects occurring within the context of a particular pattern, independent of their spatial distribution. Based on this approach we have identified numerous systematic defects including a residue defect that is described as an example in this paper. Once identified, spatial pattern can be better visualized via use of wafer map and the severity of particular defect type can be understood via resulting pareto chart.

By comparing the results against the design layout, specific failure locations in the design were confirmed. Then, the defect types were further confirmed using SEM and FIB. This novel binning technique allowed users to quantify systematic defect types quickly and efficiently from wafer maps that consist of random and systematic defects, and the analysis enabled users to take prompt corrective action.

The Challenge of Systematic Defects

Systematic defects, generally pattern failures due to process or design marginality or parametric failures due to electrical issues, are growing in importance as a factor in overall yield loss (**Figure 1**).[1] Our work here was primarily concerned with pattern-related systematic defects. Examples of systematic pattern failures include line-end thinning, necking, CD variations, side profile variation, overlay error, broken lines, and edge residues. Some of these failure modes are illustrated in **Figure 2**.

Such systematic issues can be challenging to identify using in-line defect inspection systems. Highly sensitive defect inspection is required to detect them; plus it can be difficult to identify systematic defects of interest within a high volume of other defect types, or noise-related nuisance sources. Since all systematic defects must be identified during process development, inspection recipes are often deliberately set with high sensitivity, even at the cost of potentially including large numbers of nuisance defects. The defect count can be upwards of hundreds of thousands per wafer, especially in the process development environment.

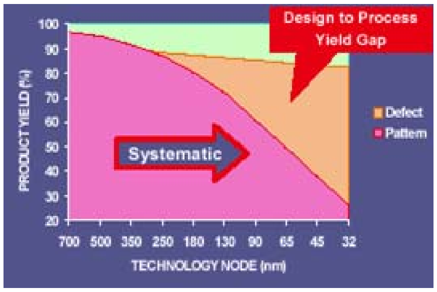


Figure 1: Systematic defects are increasing in advanced processes

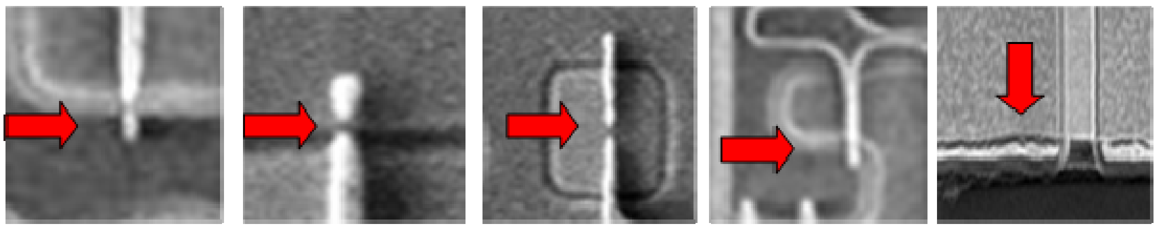


Figure 2: Sample pattern-related systematic defects (images courtesy of UMC)

After inspection, defects must be reviewed to identify their type. A typical repeater analysis based on die-to-die comparison may not be sufficient to detect defects such line-end thinning or broken lines because the failure sites are not consistent among various die. Such randomly distributed structural systematic failures are compounded when combined with high defect count. Because of the time and effort required, defect review sampling is often limited to 50 to 100 defects per wafer. With 100,000 defects, a review sample of 100 represents only 0.1 % of the total population, enormously diminishing the probability of identifying critical systematic defects during defect review.

To reduce the difficulty of identifying randomly distributed structural systematic failures, a new design-based inspection technique from KLA-Tencor was evaluated. This advanced technique has been used for almost two years, generating valuable results for both 65 and 45nm development. The integration of design data with defect data enabled us to bin defects using the design background as a proxy for SEM review.

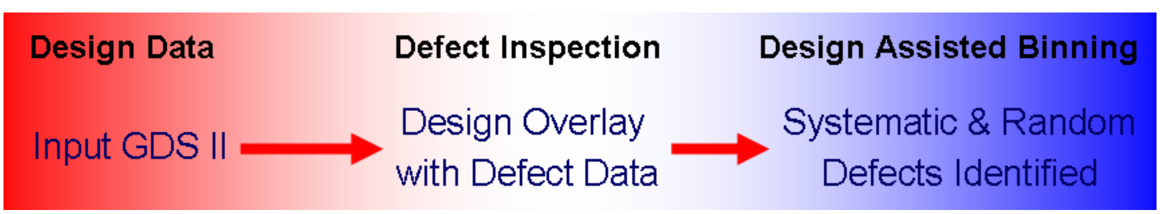


Figure 3: Illustration of applying design data to inspection data, to help separate systematic from random defects.

Example Systematic Defect: Residue Defect in STI

Within the shallow trench isolation process, a residue defect was discovered using random SEM review after inline defect inspection, however quantity and spatial distribution were unknown due to sampling limitation. (**Figure 4**). For this reason, some of the systematic defects can be missed from being recognized as systematic defect. In this study, the inspection result was first analyzed using a traditional approach (**Figure 5a**). Even with the relatively low total defect count on the wafer, the review sample of 50 defects per wafer, selected either at random or using defect size information, represented less than 10% of the total population. It was very difficult to quantify the occurrence of the residue defect and to identify its spatial signature. As a consequence, the largest bin in the defect Pareto was the 'unclassified' bin. Only a small number of defects were identified as the residue defects in the traditional defect Pareto.

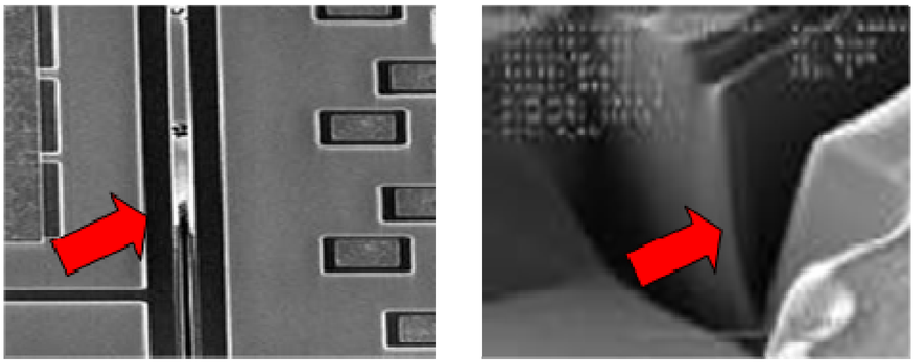


Figure 4: SEM images of the residue defect (Image courtesy of UMC)

To understand how the new technique might better quantify the residue defect population, the same data set was analyzed using both defect and design information (**Figure 5b**). Each defect location was associated with, and then grouped by, the background patterns defined in the design. After grouping, a smart sample of defects was chosen for review. With this approach a significantly different Pareto was generated, and not only 50 defects, but all defects in the inspection result were classified. Such a technique provided a unique advantage in selecting the right set of defects for review, optimizing the return on the defect review effort, and quantifying an unknown failure mode that may otherwise have been overlooked.

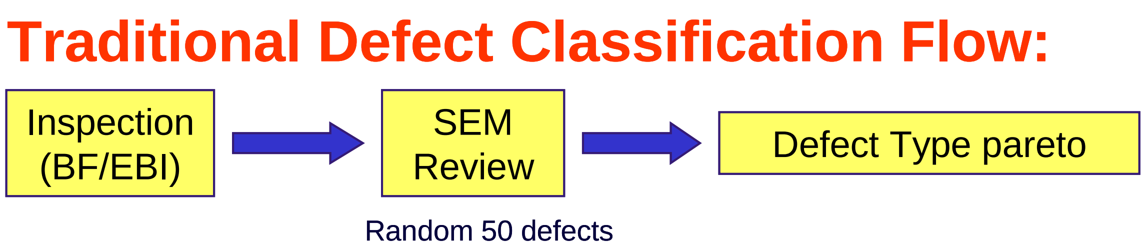


Figure 5a: Traditional approach: Some DOI (defect of interest) may be missed by the limited random sampling method.

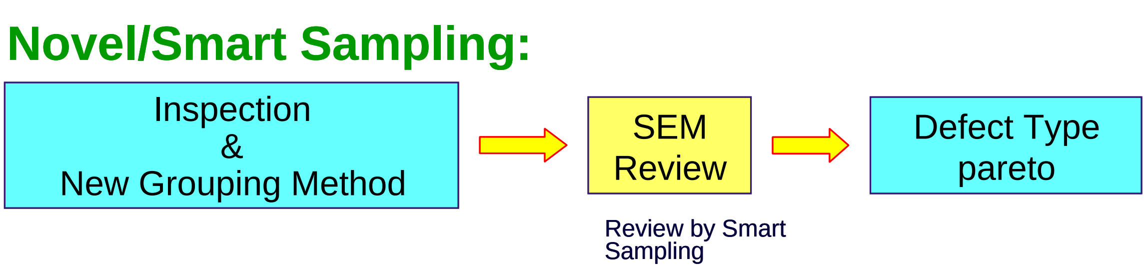
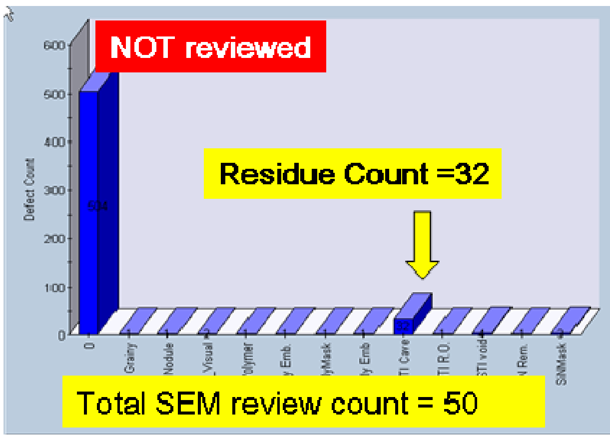


Figure 5b: New technique: By applying the new pattern grouping method before SEM review, sampling can be shaped to focus on major defect types of interest.

Results

Figures 6a and 6b compare the resulting Paretos using the traditional and new approaches. In the traditional approach, only 5% of the total defects were identified as residue defects, while the majority of defects remained unclassified. By applying the new technique, all defects were classified in the Pareto chart. With the new technique, residue defects were identified at a rate of more than 13 times the number identified using the traditional approach. With a significantly higher number of defects now identified as the defect type of interest, their spatial signature can be clearly understood, as shown in Figure 6c.

We found that the residue defects were structurally systematic, but spatially random within some of the die. While the defects seemed to occur in a certain pattern within the die, the failures did not occur at the same locations, according to a die-to-die comparison. By applying design data, we were able to identify that certain parts of the design are prone to this type of failure. Figure 7 illustrates the high probability locations of failure sites for the residue defect type.



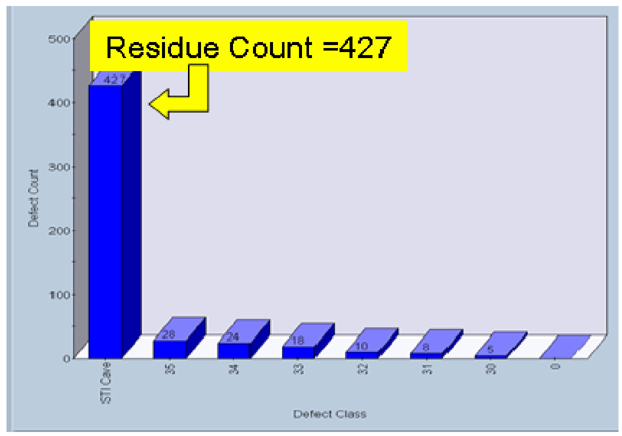


Figure 6a: Pareto using traditional defect review. Figure 6b: Pareto using new, design-based technique.

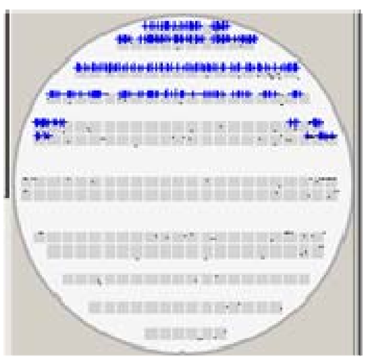


Figure 6c: Spatial signature of the residue defect (highlighted).

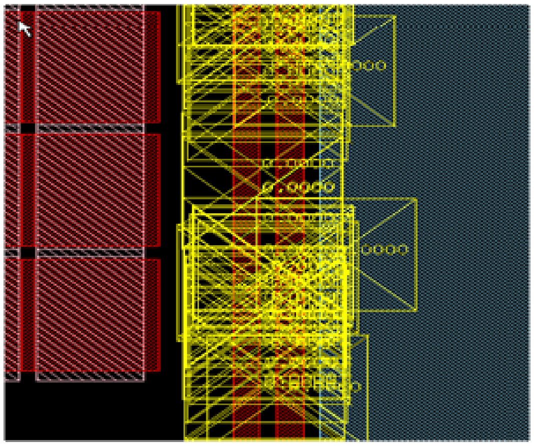


Figure 7: Illustration of defect by using design data. (Image courtesy of UMC)

Conclusion

A new technique was discussed that provides significant advantage in identifying systematic defects, using design information associated with the defect locations. The new technique relies on an inspection tool with sufficient sensitivity and location accuracy to achieve the results that we have obtained. Using the new design-based inspection technique, unknown systematic defects can be identified and quantified quickly, leading to rapid root cause discovery and correction. While the traditional approach typically samples small portion of overall population, using the new approach allows user to sample 100% of defects by using design as proxy to SEM review. This kind of structurally systematic, but spatially random defect typically occurs within a fraction of the die; because it does not occur at the same locations, a die-to-die comparison is not suitable in identifying the problem. Using the design data as an integral part of the inspection, we significantly increased our ability to identify those parts of the design most prone to this type of failure.

Acknowledgements

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Reference

[1] Monahan K and Trafas, B. Design and Process Limited Yield at the 65nm Node and Beyond. SPIE 2005.

About the author

Allen Park received his B.S. degree in Physics from University of Irvine, California, in 1988 and is now a marketing manager at KLA-Tencor Corp. He has been at KLA-Tencor Corporation for over 12 years where he engaged in yield enhancement projects as Senior Yield Consultant and Product Manager. Prior to K-T, he has worked in process development and yield enhancement at National Semiconductor and Silicon Systems.