Accelerating litho technology development for advanced design node flash memory FEOL by next-generation wafer inspection and SEM review platforms

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ABSTRACT

Development of an advanced design node for NAND flash memory devices in semiconductor manufacturing requires accelerated identification and characterization of yield-limiting defect types at critical front-end of line (FEOL) process steps. This enables a shorter development cycle time and a faster production ramp to meet market demand. This paper presents a methodology for detecting defects that have a substantial yield impact on a FEOL after-develop inspection (ADI) layer using an advanced broadband optical wafer defect inspector and a scanning electron microscope (SEM) review tool. In addition, this paper presents experimental data that demonstrates defect migration from an ADI layer to an after-clean inspection (ACI) layer, and provides clear differentiation between yield-impacting critical defects and non-critical defects on the layers. The goal of these studies is to determine the feasibility of implementing an inspection point at ADI. The advantage of capturing yield-limiting defects on an ADI layer is that wafers can be reworked when an excursion occurs, an option that is not always possible for ACI layers. Our investigation is divided into two parts: (1) Inspection of an ADI layer with high sensitivity to find an accurate representation of the defect population and to gain understanding on the propagation of defects from the ADI layer to the ACI layer; and, (2) Inspection of an ACI layer to develop an understanding of unique defects generated by the ACI process step. Overall, this paper discusses the advantages of baselining defectivity at ADI process levels for accelerated development of advanced design node memory devices.

Keywords: FEOL, ADI, ACI, Broadband Optical Wafer Defect Inspector, SEM Review Platform

1. INTRODUCTION

With continuous technological advancements in the semiconductor industry, there is a constant drive to attain smaller critical dimensions for IC fabrication. As design rules shrink, the critical defect size that impacts yield and device performance also shrinks. The timely detection of these critical defects is important for accelerating development and production ramp of leading-edge electronic devices. In addition, new materials, structures and processes introduced at advanced design nodes can introduce new defect types that have a great impact on the yield and performance of these devices. These smaller defects and new defect types often evade detection by conventional inspection tools, necessitating the use of an advanced broadband inspection tool to achieve the sensitivity required to detect the critical defects that can help engineers solve process issues for improved yield and device performance. In addition to detecting smaller defects and new defect types, it is important to explore inspection methodologies that detect yield-limiting defects as soon as
possible after the process step that caused the defects. Earlier detection of critical defects can help prevent propagation of yield issues as wafers move through the line and can aid engineers in quickly identifying the defect root cause. In some cases, early detection of yield-limiting defects also enables wafer re-work, reducing overall cost. For these reasons, we examined the relative inspection performance on ADI and ACI process layers (Figure 1) for an advanced design node flash memory device.

Identifying lithography-related defects that affect yield or device performance at ADI can be useful as wafers can be re-worked when an excursion is detected. ADI inspection methodology also has the potential to shorten device development and production ramp. However, ADI can be a challenging inspection point because the key defects of interest can have low contrast and the transparent top-level resist can cause the inspection to report a large number of prior-level defects. These ADI inspection challenges often push the inspection point to the ACI process layer. While ACI can be a less-challenging inspection point, this inspection strategy lengthens the feedback loop, potentially wasting time and materials as wafers continue to run through the line until lithography-related defect issues are identified. Also, wafers inspected at ACI cannot be easily re-worked, potentially increasing the wafer scrap and cost.

This paper characterizes yield-limiting defects on FEOL ADI and ACI layers using the 2900 broadband inspector and the eDR-7000 SEM review tool. In addition, the paper presents the results from detailed studies that followed defect progression from the ADI layer to the ACI layer. These studies allowed us to correlate the wafer defectivity at the two layers, enabling the differentiation between critical and non-critical defect populations. Finally, the data presented in this paper support the introduction of the ADI layer as an additional inspection point.

![Figure 1: Basic process flow steps from after-develop inspection (ADI) through after-etch inspection (AEI) to after-clean inspection (ACI).](image)

2. EXPERIMENTAL SETUP

This study utilized an active ADI process layer from an advanced design node flash memory device. Active ADI layer is specifically chosen for this study as defect detection at one of the early process steps is very crucial to the yield. Wafer defect inspection was performed using KLA-Tencor’s 2900 broadband optical inspection tool. KLA-Tencor’s eDR-7000 electron-beam review tool was used to capture high-resolution SEM images of the defects. High review throughput was achieved by driving the highly accurate stage directly to the defect location (DDL mode), with a 1µm field of view (FOV). After collection of all the required inspection and review data at ADI, the same wafer was processed through to ACI. The ACI layer was then characterized using the advanced broadband inspector and SEM review tools. To understand the defect migration from ADI to ACI process, the inspection and SEM review results from both the layers were analyzed. A defect correlation study was conducted to identify and understand any additional defects on the ACI
layer that were not present on the ADI layer. Similar study at ADI/ACI levels was also conducted on a previous generation broadband tool to assess the relative performance of inspector tools. In addition, a CD SEM evaluation was performed at ACI level to understand the effect of latest generation broadband inspector tool on the photoresist of ADI layer.

**Inspection recipe setup for ADI and ACI layers:** A recipe on an inspector sets the values of the inspector’s multiple optical and algorithm parameters. Each parameter must be properly tuned so that when the recipe is run, the inspector captures yield-critical defects at a low nuisance rate. Recipe creation is a process which involves thorough investigation of all the parameters available on the tool to achieve accurate characterization of the defect population, with sensitivity that ensures the detection of smallest yield-limiting defects. The inspection recipes that can provide the best sensitivity to defect population on the wafer were generated at both ADI and ACI layers.

### 3. RESULT AND DISCUSSION

The results of this study are broadly categorized as Sensitivity study at ADI/ACI layers, ADI-to-ACI defect correlation analysis, Inspector tool comparison, and CD SEM analysis

**Sensitivity study at ADI Layer:**

A very detailed investigation was pursued to achieve the highest inspection sensitivity on the ADI layer. The final inspection recipe used a new inspection mode and advanced aperture available only on the 2900 broadband platform to achieve the best sensitivity, and allowed detection of sub-20nm defects with a good capture rate. These features are not available on previous-generation broadband or laser-based inspection tools and proved key to enabling detection of sub-20nm defects. The high level of inspection sensitivity achieved using the 2900 tool makes it the tool of choice for ADI layer inspections. The inspection result on a limited sample plan is shown in Figure 2. The defect population from the entire wafer consisted of bridge, line bending, scum bridge, particle, protrusion and scum residue. SEM images for each of these defect types are shown in Figure 3.

**Sensitivity study at ACI layer:**

Similar to the ADI layer, a thorough recipe creation process was followed at the ACI process level to capture the maximum number of yield-limiting defects with the smallest size. The final inspection recipe resulted in detection of a broad defect population which consisted of mainly bridges, protrusions and line bendings on full wafer. The inspection result on a limited sample plan is shown in Figure 4.
Figure 2: 2900 Broadband inspector results on ADI layer.
Figure 3: Defect gallery for ADI layer (FOV: 1 µm).
The eDR-7000 SEM review tool played an important role in achieving inspection sensitivity entitlement for both layers in this study. The SEM review tool’s defect location accuracy allowed the use of DDL to grab high-resolution defect images at 1µm FOV. The ability to capture defect images at such a small FOV enabled clear resolution of sub-15nm defects that would not have been visible at a larger FOV. The scatter plot in Figure 5 shows the defect location accuracy of the SEM review tool at a 1µm FOV, clearly demonstrating the effectiveness of the tool.

Figure 4: 2900 Broadband inspector results on ACI layer.

Figure 5: Scatter plot representing the defect location accuracy of the eDR-7000 SEM review tool at 1µm FOV.
ADI-to-ACI defect correlation study:

The study of defects at both ADI and ACI layers resulted in several interesting findings. The correlation of defects between the ADI and ACI layers helped us understand what types of defects are transferred from the ADI layer to the ACI layer at this advanced design node and whether or not they will impact yield. For example, a very small particle on the ADI layer did not get transferred to the ACI layer and would not have any yield impact. In contrast, a scum residue at the ADI layer was transformed into a bridge at the ACI layer and would have a substantial impact on yield and device performance. Also, this study helped us understand what kinds of defects are added due to the processing steps from ADI to ACI. The results show that a small number of line bending defects appeared on the ACI layer that were not present on the ADI layer. This information can help a process engineer understand the process, providing guidance on what improvements or changes should be made to the process to eliminate yield-critical defects. Finally, it was observed that approximately 95% of the real defect population captured on the ACI layer was also caught during inspection of the ADI layer. This observation strongly suggests that an inspection point at the ADI process layer using the 2900 broadband tool can effectively monitor wafer defectivity for these advanced design node devices. Figure 6 shows several examples of defect migration images from the ADI layer to the ACI layer.
Figure 6: Defect migration images from ADI to ACI layer (FOV: 1 µm).
Inspector Tool Comparison:

In addition to the above study, results are compared across 2900 broadband and previous generation inspector tools at both ADI and ACI layers on a limited sample plan. The results are shown in Figure 7 and Figure 8 respectively. It’s clearly seen that the 2900 broadband inspector has much greater sensitivity than the previous generation tool at similar nuisance rate on both ADI/ACI levels.

Figure 7: Inspector tool comparison at ADI layer

Figure 8: Inspector tool comparison at ACI layer
CD SEM Measurement Analysis:

To assess the potential impact of a wafer inspector tool on a photoresist layer, 1, 5, 10 and 20 scans were run on 4 different dies respectively on ADI layer. CD variation was then measured at 10 reference points on each of the dies at ACI layer. The results are shown in Figure 9. It’s clear that the effect of multiple inspection scans using 2900 broadband tool on photoresist of ADI layer is minimal and it can be safely used in production scenarios.

![Figure 9: CD SEM Measurement Analysis for 2900 inspection scans](image)

4. CONCLUSION

We have achieved inspection sensitivity entitlement on both ADI and ACI layers using the 2900 broadband inspector and have successfully characterized the defect migration from the ADI layer to the ACI layer. Based on this data, Samsung believes that yield-limiting defects on the ACI layer can be detected earlier, on the ADI layer, and thus the ADI layer can be used as the first inspection point for helping obtain improved yield and device performance.
5. REFERENCES