Correlation of Wafer Backside Defects to Photolithography Hot Spots Using Advanced Macro Inspection

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ABSTRACT

Defects on the backside of a wafer during processing can come from many sources. Particles and scratches on the backsides of wafers can be caused by wafer handling equipment such as robots and chucks, as well as by CMP processes. In addition, cross-contamination of wafers and handling equipment can occur when wafers move from tool to tool, through the production line. When wafers are exposed, backside defects can cause localized areas of poor lithography pattern resolution on the frontsides of wafers, resulting in increased rework rates, decreased throughput, and yield loss.

As minimum feature sizes continue to shrink with each new technology node, devices become denser and exposure tool depth of focus decreases – making the elimination of lithography hot spots an even more critical issue.

At a major worldwide DRAM Manufacturer, automated macro defect inspection tools for integrated front, edge, and backside inspection have been implemented to inspect wafers at After Develop Inspection (ADI) and After Clean Inspection (ACI) steps. These tools have been used to detect foreign material and scratches on the backsides of several lots that were caused by another process tool, causing photolithography hot spots. This paper describes advanced macro inspection of wafer front and back surfaces and how the inspection data was used to correlate backside defects to photolithography hot spots, and take corrective action.

Keywords: Backside, Defects, Photolithography, Hot Spots, Macro Inspection, Semiconductor, Process Development

1. INTRODUCTION

Detection of front surface defects on wafers has traditionally been of primary concern to semiconductor device manufacturers, while little attention has been paid to defects located on the backside. However with advancing technology nodes, semiconductor device manufacturers have become increasingly aware that defects located on the backside can have a significant impact on yield, rework rates, and scrap. Backside scratches and particles, in particular, can contribute to photolithography issues by distorting wafer flatness during exposure and causing photolithography hot spots. If the hot spots are detected prior to etch, wafers can be reworked; otherwise, the wafers must be scrapped or will have significant yield loss. Ideally, root cause analysis should be carried out but proper analysis requires the ability to inspect both the backside and frontside of the product wafer, to correlate the inspection results and to identify the various backside defects that may be causing the problem.

One possible solution is to use existing patterned frontside and unpatterned backside inspection tools to perform the two inspections separately and, at a later stage, combine the resulting wafer maps to match backside defects against frontside yield issues. However, this method requires several manual intervention steps and therefore, creates inefficient feedback and throughput conditions.

If the backside inspection tool is a laser-based inspection system, it presents another set of challenges. Current laser-based inspection systems are designed for micro-inspection, and while their high sensitivity can pick up very small defects, their macro-inspection capability is not ideal due to inaccurate reporting of macro-defect sizes and coordinates.

In photolithography inspection applications, it is the larger macro-defects that have the most impact on frontside yield because they can cause greater warpage to the front surface of the wafer. In addition, laser-based inspection tools can only capture the scattering profile of the defect. This data is insufficient for determining the source of the defect and often requires further optical or SEM review.
Unfortunately, optical or SEM review of the backside of a product wafer requires flipping the wafer upside down, causing the front wafer surface to be in direct contact with the wafer chuck. This type of manual review not only destroys the product wafer, it also contaminates the wafer chuck.

Therefore, a more appropriate tool for this type of process monitoring is a high throughput macro-inspection system capable of inspecting both the frontside and backside of a patterned wafer, capturing color images for offline review and generating an integrated wafer map for further correlation study.

2. INSPECTION METHODOLOGY

The customer uses an AXi Series frontside inspection system with integrated backside (B20) and edge (E20) inspection at several ADI and ACI inspection steps. The AXi scans the product wafer, acquires images and compares the acquired images against a dynamic die model, allowing the system to detect a wide range of process variation and wafer anomalies, including defocus and other pattern defects. The B20 system detects a variety of backside defects including scratches, pits, stains, residuals, and particles. It scans the wafer and performs an unpatterned wafer inspection using either darkfield or brightfield illumination. The wafer center and wafer orientation are calculated in order to accurately determine and report XY coordinates of defects. Determining the defect location is critical for the purpose of accurately correlating backside and frontside defects, as well as sharing the defect locations with other defect review tools (optical and SEM). The B20 uses a color camera to collect the images, enabling the system to provide defect color, morphology and sizing data. This additional data set can prove valuable during root cause analysis especially if backside review of a patterned wafer is not possible due to the high scrap cost.

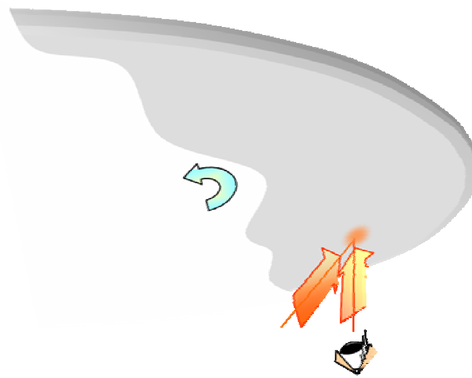

Figure 1. The B20 camera uses brightfield or darkfield illumination and a color camera to collect images as the wafer rotates.

Over the past six months the customer has implemented this all-surface inspection system as part of a comprehensive process control program, initially on an experimental basis on a single layer. While a number of more traditional inspection systems are used throughout the fab including separate front and backside inspection systems, all-surface macro inspection has been deployed with the goal of achieving a more comprehensive After Develop Inspection (ADI) while producing more immediate feedback as to possible root causes and corrective actions.

All-surface macro inspection requires that frontside and backside inspection be performed in a concurrent or serial inspection step without incurring additional overhead. Without all-surface inspection capability, an excursion would be detected as a defect on the frontside of the wafer. If a backside condition is suspected to be the cause, one or more

wafers would be transferred to a separate backside inspection tool for further analysis. This inspection flow requires additional transfer time, queuing and personnel availability. Once the backside inspection was performed, the data would then be transferred to a common database for correlation with the frontside data. Depending on the equipment used for backside inspection, actual images of these defects may not be available, requiring an additional transfer to an optical review station. (See **Figure 2**.)

Backside inspection systems typically handle wafers via edge gripping so that no patterning on the front surface is destroyed. Backside review, however, presents a major problem. Backside SEM review requires flipping the wafer, because the sample must be placed onto a vacuum chuck. This will not only destroy the frontside pattern, it will also contaminate the chuck, requiring down time for the SEM tool as the chuck is decontaminated. An alternative is to perform a simple manual optical review of the backside. This is essentially flipping the wafer over and looking at the backside under a low incidence broadband light. However, this approach is generally ineffective toward root cause analysis because the operator cannot see microscopic images or automatically drive from defect to defect.

Unfortunately, existing laser-based backside inspection tools typically do not have image capture capability. They can only document defect scattering signatures and their locations. Scattering signatures may be insufficient for performing root cause analysis because they do not contain any information about the defect color, morphology, or area. In addition, laser-based inspection tools are known to occasionally report the wrong location and size of macro-defects due to a shadowing effect. Without this richer set of defect characteristics and accurate location data, it is difficult to perform a proper root cause analysis without some type of backside review, which as previously described, presents its own set of challenges.

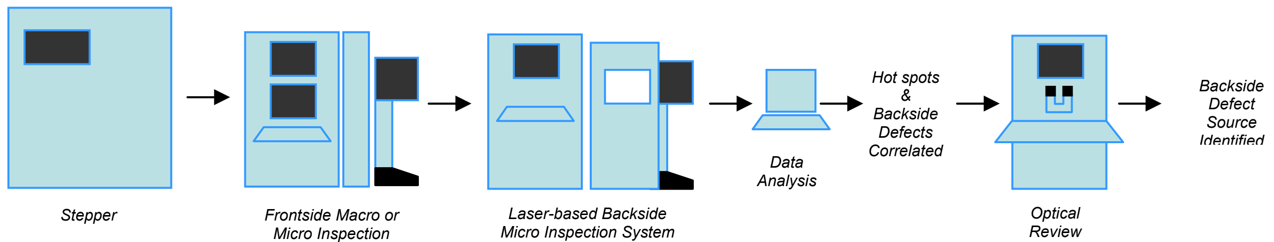

Figure 2. Diagram showing data flow for traditional hot spot detection to defect source identification. Due to separate frontside and backside inspection points and a less-optimal data set, additional data analysis and defect review are required.

By comparison, a single inspection station, capable of performing both frontside and backside inspection in a single step as shown in **Figure 3**, eliminates the need for additional transfer time between the different inspection modules. Moreover, the system can combine the frontside and backside results before sending them to a data analysis system. If the system has a built-in color image capture capability, it can eliminate costly backside optical or SEM review. Lastly, if the system is an image-based system, it may be immune from the shadowing effect and will present more accurate sizing and location data for macro-defects.

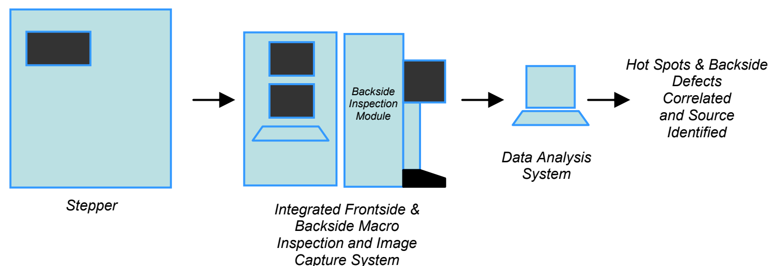

Figure 3. Diagram showing data flow for improved hot spot detection to defect source identification. Due to integrated frontside and backside inspection points and a richer data set, backside defects can be quickly identified and correlated to frontside hot spots.

The first step in creating a comprehensive ADI strategy is to correlate frontside and backside data immediately following the inspection without requiring transfer of the data to a separate data management system. Even though sophisticated fab-wide data management systems are capable of data correlation, they can be cumbersome to navigate and are not set up to automatically match frontside and backside scans of different inspection tools. Potential delays in finding the root cause of defects may increase risks and costs, ultimately leading to unnecessary yield loss.

The second step is to perform a set of controlled experiments using backside defects that can be traced throughout the lithography process. A challenge in performing root cause analysis of backside defects is that in a non-controlled environment, backside defects may move location, may be permanently squashed between the wafer and the exposure tool chuck, or may transfer to another wafer. Experiments showed that micro defects (smaller than 1μm) exhibited little correlation with frontside hot spots. Furthermore, backside detection of micro defects became impractical due excessive nuisance defects caused by common backside process variation. Controlled experiments lead to a better understanding of the characteristics of defects that will cause hot spots – mainly defects larger than 5μm. As a result, the customer was able to create a backside inspection point prior to exposure so that problem wafers are detected and rerouted prior to lithography steps. (See **Figure 4**.)

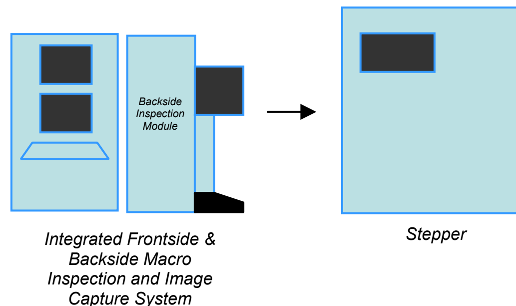

Figure 4. Diagram showing ideal hot spot prevention where backside defects are detected prior to the lithography process.

With the integrated frontside and backside macro inspection system implemented in the customer's fab, results are reported in an integrated format that can immediately be accessed including captured color images of both frontside and backside defects. This capability allows the customer to detect their hot spot problems, perform controlled experiments, characterize the killer backside defects and move from an inspection strategy that originally started after the lithography step to a strategy that starts with backside inspection before wafers are exposed.

3. PROCESS DATA (SPECIFIC EXAMPLES)

All-surface inspection was implemented in the fab to detect defects located on the front surface, backside, and edges of product wafers at several ADI and ACI steps. Backside inspection has successfully detected large defects which caused photolithography hot spots on several lots.

Example #1 – Backside Scratches

In this example, a process excursion was detected on a lot at ADI. Focus spots were seen at the same position on all wafers in the lot during frontside inspection. The lot was then scanned on a laser-based backside inspection tool. This inspection showed a large, deep scratch in the same area on the backside of all wafers in the lot (See **Figure 5**). The lot was then re-inspected on the AXi and B20 tools in order to verify the presence of the backside scratches, collect images of these backside defects (See **Figure 6**), and to correlate the locations of the frontside hot spots to the backside

scratches. Tool preventive maintenance records showed that a handler adjustment had been made to one of the coat tracks prior to processing this lot. After verification of the backside defects, the handler on this tool was re-adjusted, eliminating the root cause.

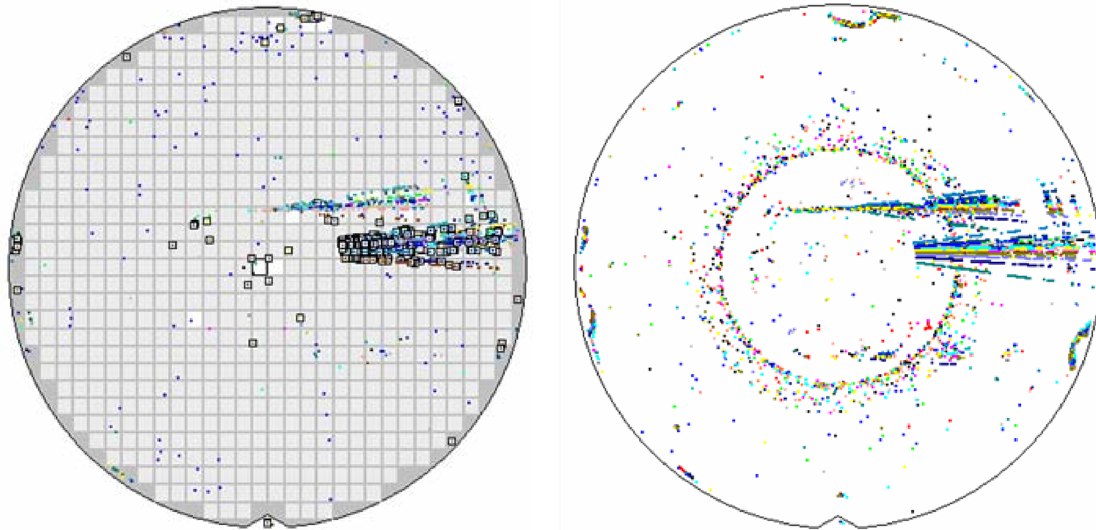

Figure 5. The wafer map on the from the AXi and B20 (left) shows a stacked wafer map of the lot, with two large scratches on the right hand side of all wafers. On the right is a stacked backside wafer map of the same lot from a laser-based inspection tool.

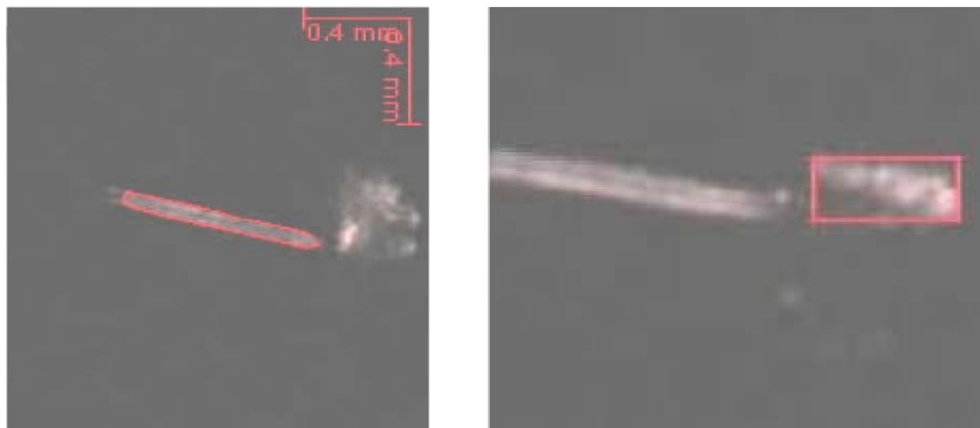

Figure 6. Darkfield images of the same backside scratch on a wafer from this lot as captured on the B20 Backside Inspection System.

Example #2 – Large Backside Particles

During all-surface inspection of a product lot at an ADI step, focus spots were detected as subtle color variations in the pattern on the frontside of a wafer. At the same time, backside inspection confirmed the existence of foreign material on the backside of the wafer at these locations. As seen in the images below, backside particles sized between 50µm – 150µm caused localized areas of poor focus. The detection of these defects at ADI allowed the lot to be flagged prior to etch.

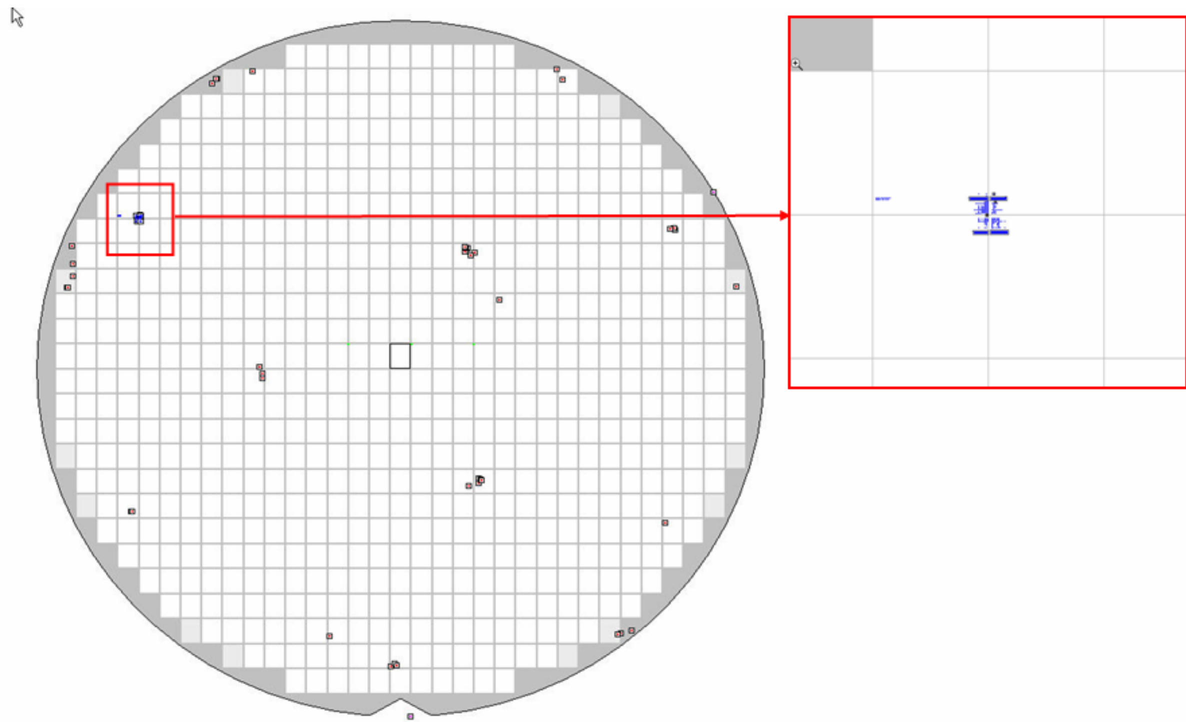

Figure 7. Wafer map shows the location of a focus spot (circled) that was detected at ADI.

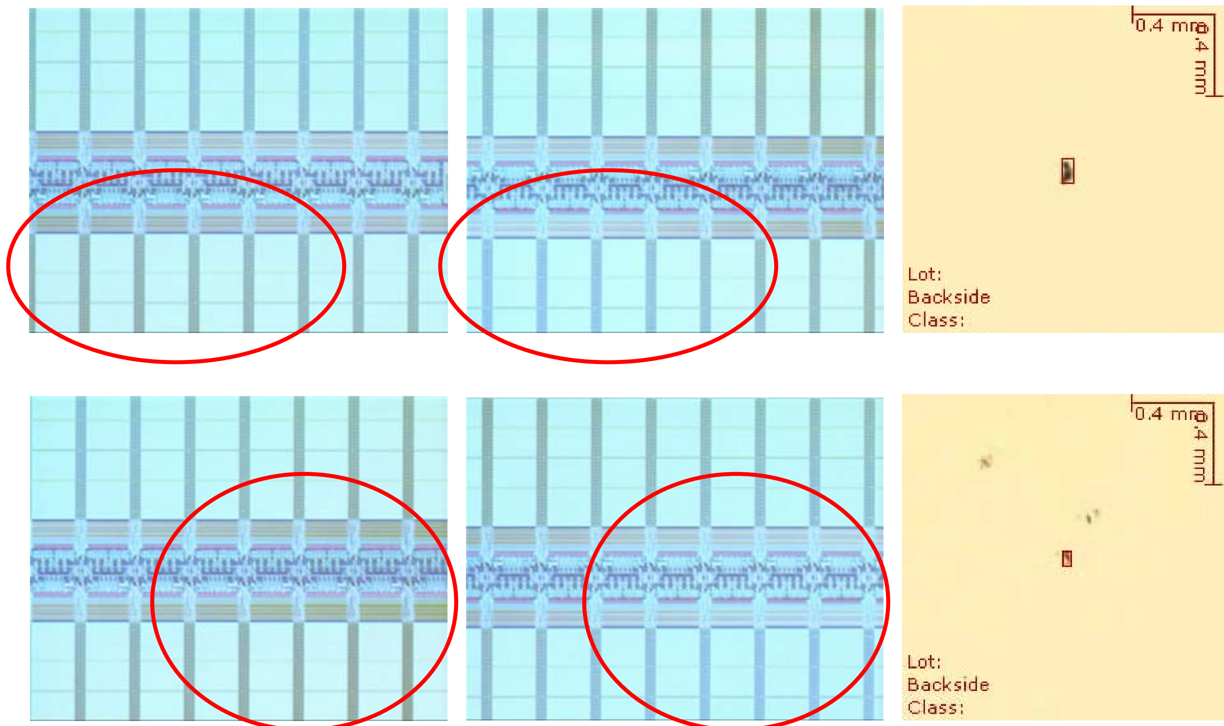

Figure 8. Focus spots were detected as subtle color changes (circled) during frontside inspection; brightfield images from backside inspection show particles sized between 50µm – 150 µm at these locations.

4. CONCLUSION

One of the goals of implementing all-surface macro inspection at this site was to achieve a more comprehensive After Develop Inspection (ADI) while producing more timely feedback as to possible root causes and corrective actions. Based on events observed in the fab, the conclusion is that combined frontside and backside ADI can reduce the number of steps and the amount of time required to identify, analyze and determine root causes. While other inspection and process control solutions exist which offer similar capabilities, an integrated solution offers more immediate feedback for the purpose of root cause analysis. Further controlled experiments showed that the killer defects exhibit certain characteristics, allowing backside macro inspection to replace the micro inspection tool set, and eventually allowing the inspection point to move before the litho step. While the scope of this experiment has been limited to a single layer, there is reason to expect that the same results can be achieved if expanded to include additional process levels.

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REFERENCES

L. Cheema et al., "Yield Enhancement from wafer backside inspection", *Solid State Technology* 46, September 2003, pp 57-60.

C. Saravanan et al., "Investigating the impact of backside defect inspection on process development and yields", *Micro Magazine*, April 2004