

Novel Full Wafer Inspection Technology for Non-Visual Residue Defects

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Keywords: Wafer inspection, non-visual residue defects, NVR, work function, contact potential difference imaging, CPDI.

Introduction

There is an unmet need today for full-wafer defect inspection for the detection of Non-Visual Residue (NVR) defects. Such NVR defects as trace metallic and organic contamination, wet-clean residues, and surface preparation anomalies can cause significant yield loss because they cannot be detected by current optical in-line defect inspection approaches. This paper describes a novel technology which permits detection of NVR defects on patterned and unpatterned wafers at a throughput which meets requirements for in-line inspection. Sample results, TXRF measurement correlation, the underlying technology, and relationship to existing techniques are described.

The Need for Full Wafer Inspection of NVR Defects

There are numerous well developed optical-based tools that quickly produce a wafer image showing the location and distribution of physical defects such as particles and scratches on semiconductor surfaces. These tools output particle contamination statistics (e.g. particle count, size distribution) routinely used for statistical process control. However, NVRs at sub-monolayer concentrations of interest cannot be detected by these tools.

A new sensing technique called Contact Potential Difference Imaging (CPDI) has been developed that enables fast, full wafer inspection for sub-monolayer chemical residues and non-uniformities across 100% of the wafer surface¹.

The CPDI technique produces data that is complementary to existing particle inspection tools, as shown in Figure 1.

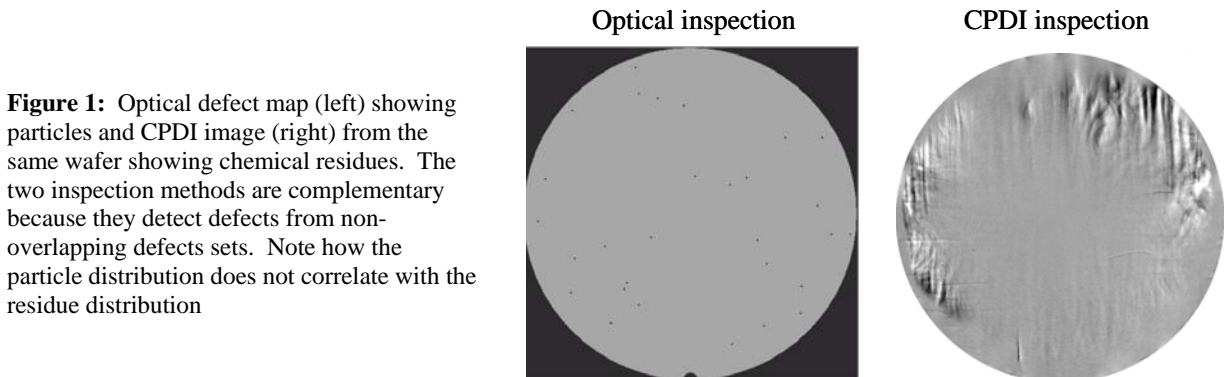


Figure 1: Optical defect map (left) showing particles and CPDI image (right) from the same wafer showing chemical residues. The two inspection methods are complementary because they detect defects from non-overlapping defects sets. Note how the particle distribution does not correlate with the residue distribution

The wafer has undergone a ST250² process followed by post-process clean. The optical inspection defect map shows the location, distribution, and number of particles on the wafer, while the CPDI

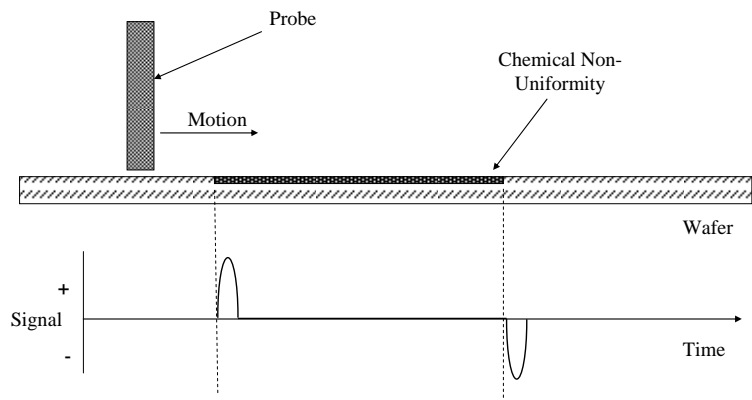
¹ All CPDI images presented in this paper were created on the ChemetriQ tool from Qcept Technologies, which exploits the CPDI technique.

image shows the distribution of chemical residues across the surface. Note that the two inspection methods provide complementary data: the sub-micron particles detected by the particle inspection tool are not detected by CPDI, while the distribution of chemical residues seen by CPDI is not detected by the particle inspection tool. Together, the full surface state of the wafer is revealed.

Novel, Non-Optical Defect Inspection Technique

The CPDI technique detects work function variations across a surface, as described in [1]. Briefly, the wafer is rotated under a stationary probe (Figure 2). Chemical non-uniformities on the surface cause work function variations that are sensed by the probe, then mapped to produce a CPDI image. The only energy input into the system is the rotation of the wafer. No electromagnetic stimulation of the wafer is used, and the probe does not touch the wafer surface. Hence the technique is entirely non-destructive to the wafer. The minimum detectable isolated feature size is approximately 30 microns in diameter; a full coverage 300 mm wafer scan takes approximately 4 minutes.

Figure 2: Schematic of CPDI probe moving over a wafer surface. The CPD signal induced by the indicated chemical non-uniformity is shown at bottom.



Metal Contamination Signal Correlates with TXRF

Figure 3 below shows the correlation between the CPDI signal and TXRF measurements for copper surface contamination. Correlations such as this can be used to set a “go/no-go” threshold limit for defect levels of interest. With such a threshold set, CPDI can be used as a screening tool to quickly detect inline NVR defects.

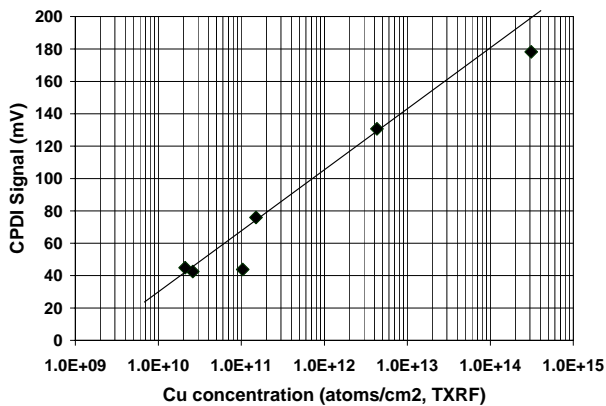
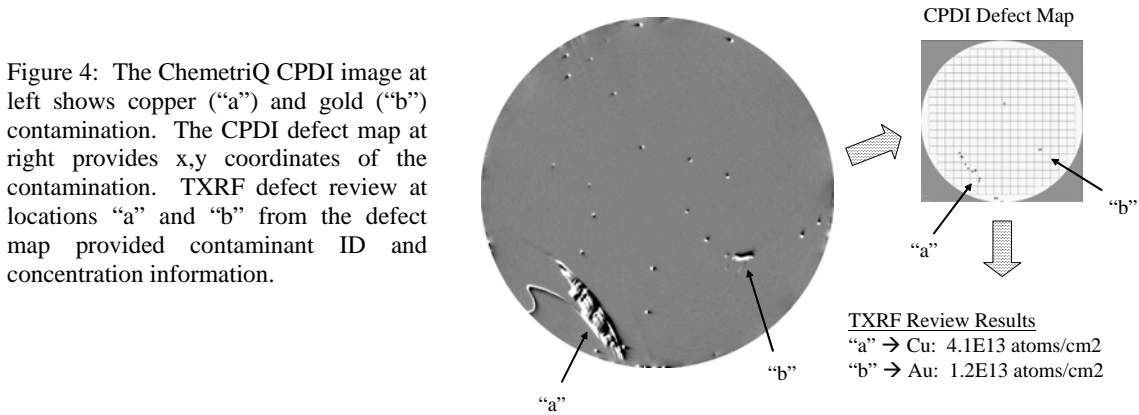


Figure 3: Correlation of CPDI signal to surface copper concentration as measured by TXRF. The lowest copper concentration deposited, 2E10 atoms/cm² in this test, was detected by the ChemetriQ CPDI tool.

² ST250, a trademark of ATMI, is a liquid chemical used to remove post etch polymer residues.

Figure 4 below demonstrates use of a CPDI defect map to direct an analytical tool to defect locations for follow-up analysis. The wafer was contaminated by physical contact with Cu and Au then scanned on the ChemetriQ CPDI system. A signal threshold was applied to create a defect map (right) and KLARF file. The TXRF was directed to the defect locations “a” and “b” by the KLARF file where TXRF spot measurements identified the contaminants and their concentrations.



Pattern and Blanket Wafer Compatibility

The CPDI technology can also be used on patterned wafers as demonstrated in Figure 5. These two wafers had undergone pattern, etch, and resist strip. The spatial signature of the resist residual on the wafer at right clearly reveals the liquid flow pattern of a single wafer clean tool, with the break in surface tension near the wafer edge clearly imaged. Such process signatures are valuable to the engineer for process troubleshooting and root cause analysis.

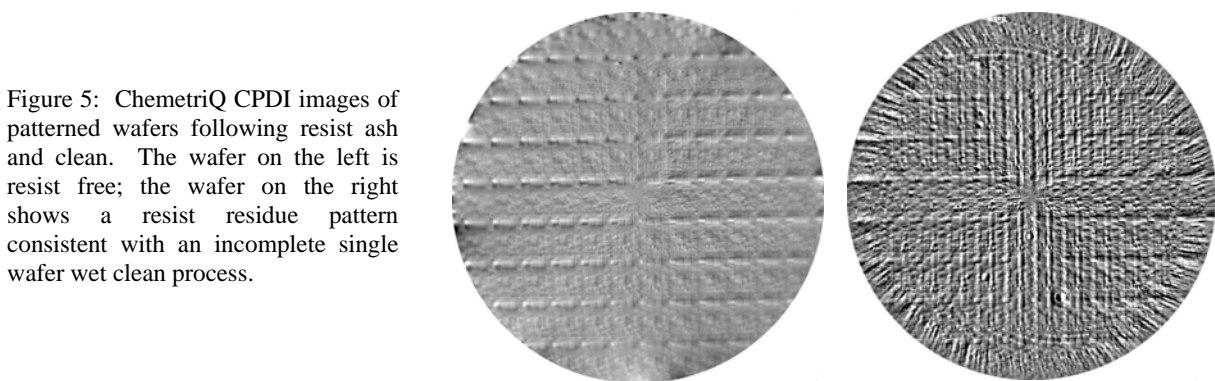


Figure 5: ChemetriQ CPDI images of patterned wafers following resist ash and clean. The wafer on the left is resist free; the wafer on the right shows a resist residue pattern consistent with an incomplete single wafer wet clean process.

NVR Full Wafer Inspection: Parallels to Physical Defect Inspection

Table I below summarizes the relationship between inspection and review techniques available for physical (e.g. particles, scratches) and chemical (e.g. NVRs and stain) defects. Full wafer optical inspection techniques, such as laser scattering, brightfield, and darkfield, find the location and

signature of physical defects on wafers. They produce defect maps and results files (typically a KLARF format file) that can be fed to other analytical tools (e.g. SEM, EDX) to efficiently characterize the defects of interest. Optical inspection tools and review tools have developed hand-in-hand to provide the process engineer with an efficient and integrated particulate detection and analysis scheme.

Table I: Examples of full wafer inspection and defect review techniques for physical and chemical (NVR) defects.

	<u>Full Wafer Inspection Techniques</u> Result: Go/NoGo Decision	<u>Defect Review Techniques</u> Result: Detailed information about defects
<u>Physical Defects</u> Particles, scratches	Optical, laser scatter	SEM, EDX
<u>Chemical (NVR) Defects</u> Metallic/organic contamination, surface prep anomalies	Contact Potential Difference Imaging (CPDI)	TXRF, XPS, TOF-SIMS

For NVR defects process engineers have historically been forced to rely on analytical instruments such as XPS, TXRF, and TOF-SIMS for both inspection *and* defect review of surface molecular residues. This arrangement is highly inefficient. While analytical tools provide useful information on contaminant identity and concentration, their throughput is too low for effective full-wafer inspection, and their results provide no clues as to the spatial signature of the defects -- crucial for efficient root-cause analysis.

With its ability to quickly produce an image showing spatial signatures, defect map, defect statistics, and KLARF file, the CPDI technique enables a use case which is analogous to that of particle inspection tools. CPDI enables rapid full-wafer *inspection* for chemical contamination and other NVR defects. CPDI inspection results can then be used to direct defect review tools (e.g. analytical tool such as TXRF) to the identified defects thereby improving review tool throughput and efficiency.

Conclusion

This paper describes using the CPDI sensing technique for full wafer inspection for non-visual residues and defects. The CPDI technique outputs a wafer image, defect map, summary statistics, and a KLARF file like a particle inspection tool. However CPDI inspection detects non-visual defects that particle inspection tools miss, thus complementing particle inspection information to more fully reveal the defectivity state of the wafer surface.

References

[1] C. Yang, J. Hawthorne, B. Steele, R. Bryant, D. Sowell, D. Maloney, K. Ip, *MICRO*, **25**, 1(2005)