Detection of Metal Contamination on Silicon Wafer Backside and Edge by New TXRF Methods

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Abstract. In conventional 200mm wafer processing, backside defects are not considered to be of much concern because they are obscured by wafer backside topography. However, in current 300mm wafer processing where both sides of a wafer are polished, backside defects require more consideration. In the beginning, backside defect inspection examined particle contamination because particle contamination adversely influences the depth of field in lithography. Recently, metal contamination is of concern because backside metal contamination causes cross-contamination in a process line, and backside metals easily transfer to the front surface. As the industry strives to yield more devices from the area around the wafer edge, edge exclusion requirements have also become more important. The current International Technology Roadmap for Semiconductors [1] requires a 2mm edge exclusion. Therefore, metal contamination must be controlled to less than 2mm from the edge because metal contamination easily diffuses in silicon wafers. To meet these current semiconductor processing requirements, newly developed zero edge exclusion TXRF (ZEE-TXRF) and backside measurement TXRF (BAC-TXRF) are effective metrology methods.

Keywords: TXRF, x-ray, fluorescence, metrology, wafer, backside, edge, contamination
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INTRODUCTION

TXRF metrology is widely used in-line for surface contamination monitoring. Generally, TXRF provides three type of measuring modes. Direct-TXRF measures discrete points (typically 3 to 9) with long count times. VPD-TXRF measures the dried Vapor Phase Decomposition droplet after decomposition and recovery of the wafer surface oxide layer using hydrofluoric acid. SP-TXRF (Surface Profiling TXRF or "sweeping" TXRF) measures many points with short count times (*e.g.* 200pts, excluding the edge exclusion area, at 5sec/pt) and is used in manufacturing processes to evaluate unexpectedly high contamination levels [2].

With the introduction of large-diameter wafers, single-wafer processing, and new materials (*e.g.* metal gate), semiconductor processes require more comprehensive wafer evaluation. To address these requirements, Rigaku developed the new TXRF functions, ZEE-TXRF and BAC-TXRF. ZEE-TXRF (Zero Edge Exclusion-TXRF) enables contamination measurements to zero edge exclusion. BAC-TXRF (Backside Analysis Capable-TXRF) enables wafer backside measurements. These new TXRF functions enable comprehensive evaluation of wafer contamination.

METAL CONTAMINATION CONTROL IN THE MANUFACTURING PROCESS

Metal contamination control levels in semiconductor processes depend on the type of devices being manufactured. Generally, metal contamination control levels are set by the required carrier life time. The relationship between typical metal contamination control levels and type of semiconductor devices is shown in Figure 1.

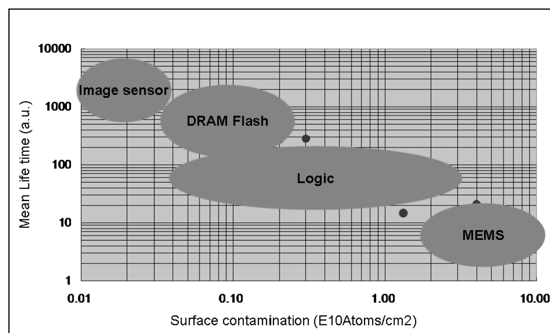

FIGURE 1. Relationship between contamination control level and device types.

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The most strict contamination control is performed in image sensor processing, such as CIS and CCD, with an E8 atoms/cm^2 control level. Memory device processes, such as DRAM and flash, are controlled around 1E9 atoms/cm^2. In contrast, MEMS processes do not have strict contamination control requirements. However, metal contamination is often a concern for the foundry that produces both semiconductor and MEMS devices.

Metal contamination analysis can be classified into three types: surface analysis, bulk analysis, and liquid analysis (Table 1).

TABLE 1. Analysis methods for metal contamination.

Method	Analysis Type	Element Analysis
Micro-PCD	Bulk	Fe only
SPV	Bulk	Fe only
C-t	Bulk	Impossible
DLTS	Bulk	Impossible
AAS	Liquid, Surface	Depending on hollow cathode lamps
ICP-MS	Liquid, Surface	About 73 elements
SIMS	Surface, Bulk	H - U
TXRF	Surface	Na - U
VPD-TXRF	Surface	Na - U

In those categories, surface analysis is the most important to evaluate semiconductor devices. TXRF is included in the surface analysis category, providing information up to a depth of about 4nm. TXRF has the following general features:

- large spot measurement (10mm diameter),
- mapping capability,
- depth analysis with angle scanning,
- ~4nm analysis depth at standard incident angle,
- easy operation,
- in-line usage, and
- E9 atoms/cm^2 level lower limit of detection.

TXRF PRINCIPLES

When the incident angle between an optically flat surface and the primary x-ray beam is gradually reduced, there is an angle at which the primary x-ray beam is completely reflected by the sample surface. That incident angle is called the "total reflection critical angle" (Figure 2).

At the condition of total reflection, interactions between x-ray photons and atoms comprising the sample are minimized. As a result, the signal-to-noise ratio is improved because background intensity caused by scattering of the primary x-ray beam is reduced.

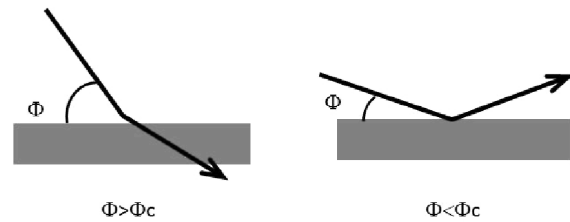

FIGURE 2. Total reflection phenomenon.

To a first-order approximation, the total reflection critical angle is expressed as [3]:

$$\phi_c = 2.32 \cdot 10^5 \cdot \lambda \cdot \left(\frac{\rho \cdot Z}{A}\right)^{\frac{1}{2}} \quad (1)$$

where ϕ_c is the critical angle in radians, λ is the wavelength of the primary x-rays in cm, ρ is the sample density in g/cm^3, Z is the atomic number, and A is the atomic weight.

LOWER LIMITS OF DETECTION

The Lower Limit of Detection (LLD) is used as an index of TXRF performance. The following equation is normally used to calculate such a detection limit [4]:

$$LLD = 3 \times \frac{\sqrt{BG \times T}}{T} \times k \quad (2)$$

where BG is the background intensity in cps, T is the measuring time in sec, and k is a calibration coefficient. Typical detection limits for elements measured by Direct-TXRF are shown in Table 2.

TABLE 2. Typical detection limits for Direct-TXRF.

Atomic Number	Element	LLD x E10 [atoms/cm^2]
11	Na	20
13	Al	8
19	K	2.2
20	Ca	1.4
22	Ti	0.5
24	Cr	0.2
26	Fe	0.1
27	Co	0.1
28	Ni	0.1
29	Cu	0.2
30	Zn	0.3
39	Y	1.8
40	Zr	1.8
41	Nb	1.7
42	Mo	1.8
74	W	2.8
78	Pt	2.0
79	Au	1.9

Detection limits are two orders of magnitude improved when VPD-TXRF is applied to a 300mm wafer.

ZEE-TXRF, ZERO EDGE EXCLUSION TXRF

The Edge Bead Removal (EBR) range, upper bevel, apex, and under bevel (Figure 3) are readily contaminated by metals and particles. As those contaminants diffuse into the wafer bulk or surface, defects may form. For many years, edge area metal contamination was not measured for lack of suitable metrology tools. As processing and metrology techniques advance, manufacturers attempt to yield devices out to the wafer edge. The economics of this kind of yield improvement are illustrated as follows. Consider a 300mm wafer with a 10mm edge exclusion. The edge area represents 13% of the total wafer area. If 150 chips can be created in the edge area at $5 profit per chip, and 10,000 wafers are processed, the edge area represents $7,500,000 of potential profit.

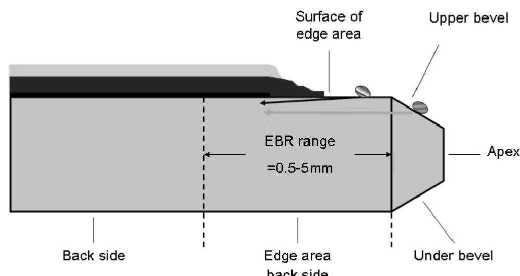

FIGURE 3. Wafer cross section near the edge.

The Defect Detection Technology Requirements table in the ITRS [1] specifies a 2mm edge exclusion out to the year 2013. However, in 2009 many device manufacturers request 1mm edge exclusion of test equipment manufacturers. In accordance with market demands, Rigaku developed ZEE-TXRF that offers TXRF measurements out to zero edge exclusion.

Development of ZEE-TXRF

Rigaku introduced its first TXRF spectrometer, the 3725, in 1988, when 200mm wafers were first being adopted in the semiconductor industry. The incident x-ray beam in a TXRF tool strikes the wafer surface at a glancing angle (typically <0.1°).

Figure 4 shows the relationship between the primary x-ray beam, sample stage, and detector in a conventional TXRF tool configuration. In that case, the detector is positioned to minimize the path length of the primary x-rays while still being able to measure the entire wafer surface. However, the primary x-ray beam hits the wafer edge, causing x-ray scattering that could produce:

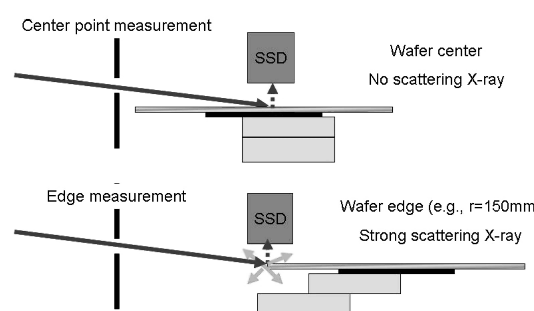

FIGURE 4. Conventional TXRF.

- high background intensity levels that degrade detection limits,
- high detector dead time rates that degrade quantitative accuracy and throughput, and
- spurious and interfering "ghost peaks" resulting from scattered x-rays interacting with the hardware and then reaching the detector.

Before ZEE-TXRF, it was necessary to enforce a suitable edge exclusion, typically 15mm, to avoid such edge-scattering effects. To solve the problem of edge scattering, the detector position and stage motion were changed as shown in Figure 5. As a result, incident x-rays irradiate from the opposite direction to the conventional method, and edge scattering does not appear even when the edge is measured. However, the primary x-ray beam path was extended, so new x-ray optics were developed for ZEE-TXRF with an optimized focusing point to avoid sensitivity loss.

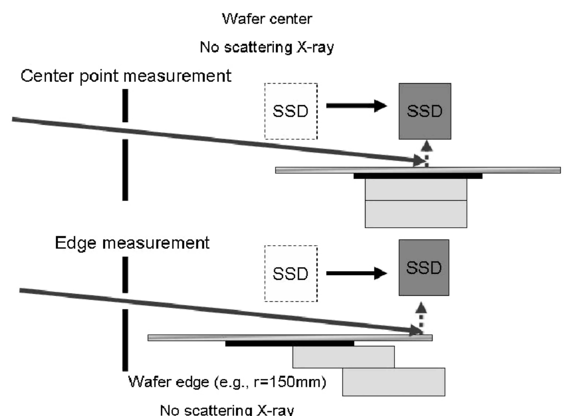

FIGURE 5. ZEE-TXRF.

Applications of ZEE-TXRF

The following examples illustrate applications of ZEE-TXRF.

Contamination of a Three-Point Edge-Handling Robot

Figure 6 shows Cr, Fe, and Ni contamination at the same edge locations as the robot contact points, indicating that stainless steel contamination was transmitted. Without ZEE-TXRF, only the region within the inner circle is measurable, and the edge contamination would not have been detected.

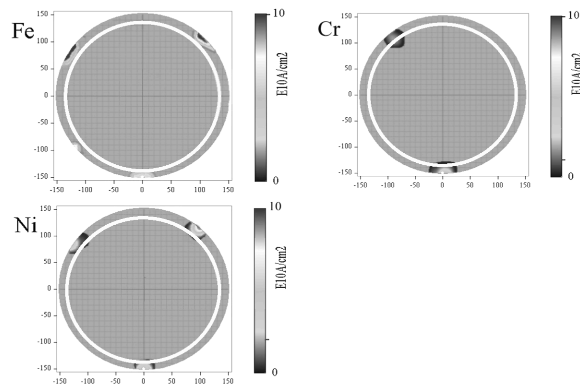

FIGURE 6. Contamination from a three-point, edge-handling robot. Contaminant levels [atoms/cm^2]: Cr = 2E10, Fe = 1.3E11, Ni = 1.1E11.

TXRF Measurement Linked with Particle Inspection Tool Results

Rigaku TXRF tools can import coordinate files generated from defect inspection tools. Particles tend to cluster around the edge as shown in the left image of Figure 7. The particle cluster (or scratch) detected around the edge was measured by ZEE-TXRF, from which it was determined to contain Al.

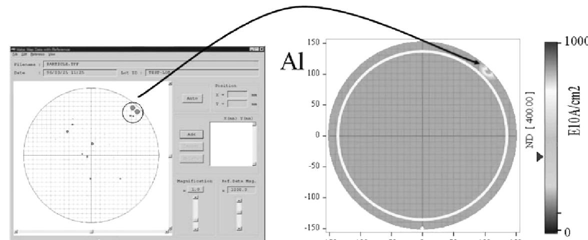

FIGURE 7. Particle analysis.

Comparing ICP-MS and TXRF Mapping Capability

Generally, VPD-ICP-MS provides much higher sensitivity than Direct-TXRF. Moreover, recent VPD preparation tools enable droplet recovery from discrete areas. Combining ICP-MS and VPD tools, mapping can be realized. The performance of ICP-MS and TXRF for mapping analysis was evaluated.

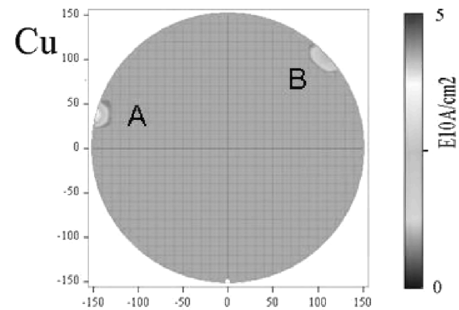

FIGURE 8. Cu contamination on the edge. Contaminant levels [atoms/cm^2]: A = 4E10, B = 2E10.

From Figure 8, Cu contamination was detected at two locations around the wafer edge. The same locations were measured by VPD-ICP-MS with mapping recovering over areas consistent with those measured by Direct-TXRF. As a result, Cu contamination was detected at location A, but not at location B. The sensitivity of ICP-MS depends on the size of VPD droplet recovery area. Sensitivity decreases when the recovery area is reduced. The ICP-MS result is shown in Table 3. From the result, Direct-TXRF has the advantage for mapping measurements. The full wafer coverage that TXRF mapping capability (SP-TXRF) provides is another way that TXRF offers comprehensive evaluation of wafer contamination.

TABLE 3. Results of Mapping Recovery ICP-MS

Recovering Position	Concentration [atoms/cm^2]
A	6.5E10
B	Not Detected
Detection Limit	2.5E10

BAC-TXRF, BACKSIDE ANALYSIS CAPABLE TXRF

In conventional 200mm wafer processing, backside defects were hidden by wafer backside topography. Doubly-polished 300mm wafers, on the other hand, can be readily inspected for backside defects. Originally, backside defect inspection sought to identify particle contamination because particle contamination has a bad influence on the depth of field of a lithography tool. Recently, metal contamination is of concern because backside metal contamination can cause cross-contamination of process tools, and backside metals can transfer to the wafer frontside, adversely affecting device yield.

Development of BAC-TXRF

Historically, backside metal contamination has not been inspected due to:

- lengthy sample preparation time,
- wafers having to be flipped by a human operator: this is not possible in a 300mm automated wafer process, and
- cost: two wafers were necessary, one for a frontside measurement and another for a backside measurement.

However, backside contamination can cause considerable damage to a process. Many new materials (*e.g.* Cu, Hf, Ta, Zr, Al, Co) are introduced in leading-edge processes, so backside contamination cannot be ignored.

Rigaku considered how to implement BAC-TXRF based on market feedback and chose a robot capable of inverting a wafer using a non-contacting end effector based on the Bernoulli principle. Although the end effector is non-contacting, the wafer ultimately contacts a measurement stage in a small central region. An edge gripping wafer handling solution was rejected because the edge region is usually of greatest interest concerning contamination.

Applications of BAC-TXRF

Contamination from metal processing readily illustrates the application of BAC-TXRF. As shown in Figure 9, after Ta and Cu films are formed, both elements can easily transfer to the wafer backside. Those contaminants can cause cross-contamination of wafers and other tools.

FIGURE 9. Metals adhering to the wafer backside.

Figure 10 shows significant residual Cu contamination around the backside edge (as a ring pattern) following film sputtering and film electroplating. The electroplating process gives especially high Cu contamination at the E13 atoms/cm^2 level. This example illustrates the combination of BAC-TXRF with ZEE-TXRF to characterize contamination in the edge area of the wafer backside.

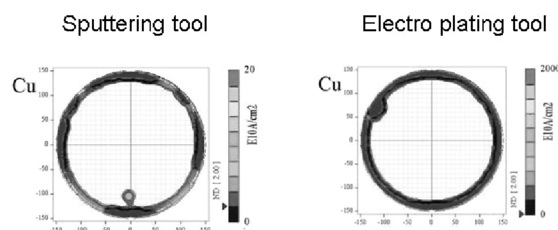

FIGURE 10. Wafer backside contamination following Cu film processing (sputtering and electroplating, respectively). Contaminant level [atoms/cm^2]: Cu = E10 – E13.

SUMMARY

Comprehensive, in-line wafer contamination metrology is important to achieve device yield goals and to prevent metal cross-contamination. State-of-the-art, in-line TXRF metrology now includes:

- Direct-TXRF for discrete measurements,
- SP-TXRF for rapid spatial mapping,
- VPD-TXRF for highest sensitivity,
- ZEE-TXRF for zero edge exclusion, and
- BAC-TXRF for backside measurements.

ACKNOWLEDGMENTS

Rigaku notes with sadness the passing of Tomoya Arai in March, 2009. He was instrumental in the early development of Rigaku XRF and TXRF tools.

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