Detection of contaminants in positive and negative ion mode using in-line SIMS with an Oxygen primary ion beam.

Authors: Julia Hoffman, Sarah Okada, Lawrence Rooney, Bruno Schueler, Ganesh Vanamu

Abstract

Utilizing Secondary Ion Mass Spectrometry (SIMS) for in-line metrology is a newly emerging method of process control that requires contamination-free measurements, enabling SIMS on product wafers. SIMS measurements of negative ions are usually associated with a Cesium primary ion beam. Unfortunately, when Cesium is present in Silicon, it forms trap states in the Si band gap, which can cause serious leakage issues for Si-base transistors. Therefore, Cesium is considered a very damaging contaminant in semiconductor devices.

On the other hand, an Oxygen primary ion source, which is typically used for positive secondary ion measurements, is the primary beam of choice for in-line SIMS since it is benign and not considered a contaminant. By switching the secondary spectrometer polarity between positive and negative ion modes, an Oxygen primary ion source can be used successfully to measure both positive and negative species.

While an Oxygen primary ion source may not provide the same sensitivity to negative secondary ions as a Cesium primary ion beam, the ability to directly measure a range of species without the risk of contamination creates a wide field for in-line SIMS applications.

In this paper, the use of an Oxygen primary ion source for positive and negative secondary ion detection is being investigated on an in-line SIMS tool. We evaluate sensitivity levels of detecting contaminants like C, F, Cl in positive and negative ion mode with an Oxygen primary ion beam, as well as the use of proxy species or alternate isotopes for improved results.

Background and Introduction

Contamination introduced during semiconductor processing is a critical concern because it can kill devices. Contaminants (like Fluorine, Chlorine, Carbon, Oxygen etc.) may be introduced from precursor impurities, reactant gases or a by-product reaction. These contaminants can also be introduced from the process chamber (from the rubbing of moving parts), from cleaning chemistry of chamber shield/liners, from excursions during preventive maintenance, and from previous process steps.

Integration and reliability issues can result from diffusion of Fluorine into underlying films or the substrate. Fluorine can cause electromigration as well as ion diffusion which could lead to device performance failures. For example, in memory applications, Fluorine diffusion into the charge trap layers can cause issues during the erase step of the memory operations.

Contaminants like Chlorine (Cl– ions) cause Al-Cu corrosion and metal cross contamination in integrated circuits that could lead to wafer scraps (1). Organic impurities (like carbon) interact with wafer surfaces to change the intrinsic properties (interface density) and film reliability in the semiconductor devices which result in serious yield issues.

There is a need for in-line monitoring of contamination. The sooner the presence of contamination can be detected, and the root cause identified, investigated, and fixed, the more wafers in the process can be saved -- reducing scrap and improving yield. Furthermore, the ability to measure the concentration of contamination as a function of depth helps to monitor strategic aspects of the process, such as barrier function, contact resistance, annealing, charge trap performance, and others, which lead to device performance.

Metrology Challenges

Detection and quantification of contaminant levels or process/etch residues, as well as the location within film layers is required. For low levels of contaminants, the Dynamic SIMS technique is of interest.

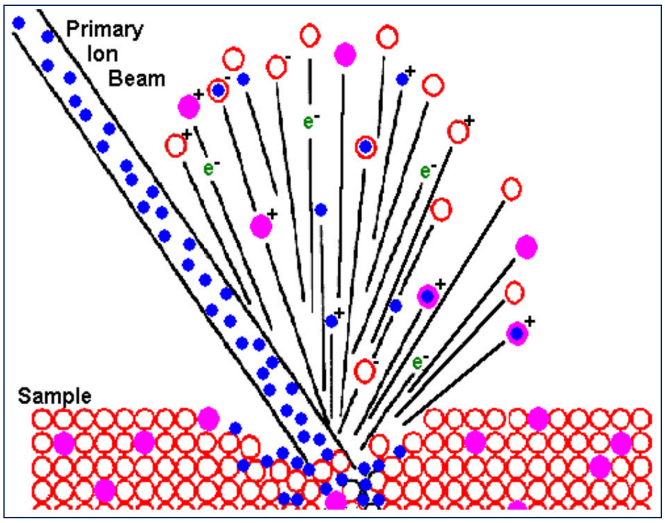

Figure 1. Basic principle of secondary ion mass spectrometry (SIMS): A primary ion beam is sputtered through sample surface layers, resulting in ejection of secondary ions, which are then separated by mass spectrometer and analyzed. Image Source: EAG Labs.

Secondary Ion Mass Spectrometry (SIMS) can detect low concentrations of impurities, providing depth profiles of ions of interest. The sample surface is bombarded with a focused primary ion beam. This bombardment causes formation and ejection of secondary ions, both positive and negative. Secondary ions are then extracted and registered with a mass spectrometer.

The conventional environment for a SIMS tool is in the analytical laboratory, where monitor wafers are usually diced into coupons and tested for production stability and level of contaminants. The process of testing may be long, leading to potential losses and result in lower chip yield since the results often do not reflect the actual production conditions on actual product wafers. In a laboratory environment switching between Cesium and Oxygen sources is a lengthy process that requires thorough purging of the system and may span several days. Alternatively, the metrology lab may have several SIMS tools set up for dedicated applications, requiring multiple coupons to be measured separately on different SIMS tools. Since each of these SIMS tools are manually adjusted with different parameters, this introduces a wider error range. In addition, single point measurements on coupons do not provide within-wafer or wafer-to-wafer distribution of the contaminant (wafer map).

Utilizing Secondary Ion Mass Spectrometry (SIMS) for in-line metrology is a newly emerging method of process control that requires contamination-free measurements, enabling SIMS on product wafers. SIMS measurements of negative ions are usually associated with a Cesium primary ion beam. Unfortunately, when Cesium is present in Silicon, it forms trap states in the Si band gap, which can cause serious leakage issues for Si-base transistors. Therefore, Cesium is considered a very damaging contaminant in semiconductor devices.

An Oxygen primary ion source, which is typically used for positive secondary ion measurements, is the primary beam of choice for in-line SIMS since it is benign and not considered a contaminant. By switching the secondary spectrometer polarity between positive and negative ion modes, an Oxygen primary ion source can be used successfully to measure both positive and negative species.

While an Oxygen primary ion source may not provide the same sensitivity to negative secondary ions as a Cesium primary ion beam, the ability to directly measure a range of species without the risk of contamination creates a wide field for in-line SIMS applications.

METRION®

Nova's METRION® is a 300mm wafer-level in-line SIMS metrology system developed to seamlessly integrate with an automated high-volume manufacturing (HVM) fabrication environment. It is a fully automated, recipe-driven metrology tool utilizing a Magnetic Sector mass analyzer to provide high quality dynamic SIMS depth profiles. It has an O2+ primary ion source that ranges from low to medium to high in beam energy for a variety of applications. By design, METRION® enables stable and repeatable measurements within a 50um x 50um metrology pad on product wafers. With multiple detectors, METRION® can measure multiple species simultaneously through the entire film stack, providing high data density capable of achieving higher depth resolution. Process automation with built-in film analysis and recipe management make the system easy to use and shorten the time to data.

Contaminant Measurement in PSIM and NSIM Modes

Here we present measurements of contaminant species (F, Cl, C) in both positive and negative ion mode (PSIM and NSIM respectively). The measurements were taken with a primary oxygen ion beam (18O2+), on a 75x75 μm raster area.

In the negative ion mode F-, Cl-, C- were measured. In the positive ion mode F+, SiF+, Cl+, SiCl+, and C+ were measured.

The ions of F and Cl are of high electronegativity; therefore, they are expected to have higher secondary ion yield in the negative ion mode. On the other hand, C has lower electronegativity value, and its yield would be expected to be not as high as for F and Cl, but still better in the NSIM mode. In cases where highly electronegative (like F, Cl) contaminants need to be measured along low-electronegativity species (like B, Ge), there is a possibility to use Silicon-bound positive ions, like SiF+, or SiCl+ (proxy).

Figure 2 shows the Cl- profile in NSIM is very similar to the SiCl+ profile PSIM demonstrates how the proxy species can be quantified to provide meaningful information on contamination levels. Sensitivity difference between measuring high-electronegativity species in positive and negative ion mode, as well as the proxy species, is shown in Figures 2-8. Depending on the species, the difference could be as high as 2.5 orders of magnitude (between Cl- and Cl+ measurement), or as low as 1 order of magnitude or less (F- and SiF+, or C-and C+ differences).

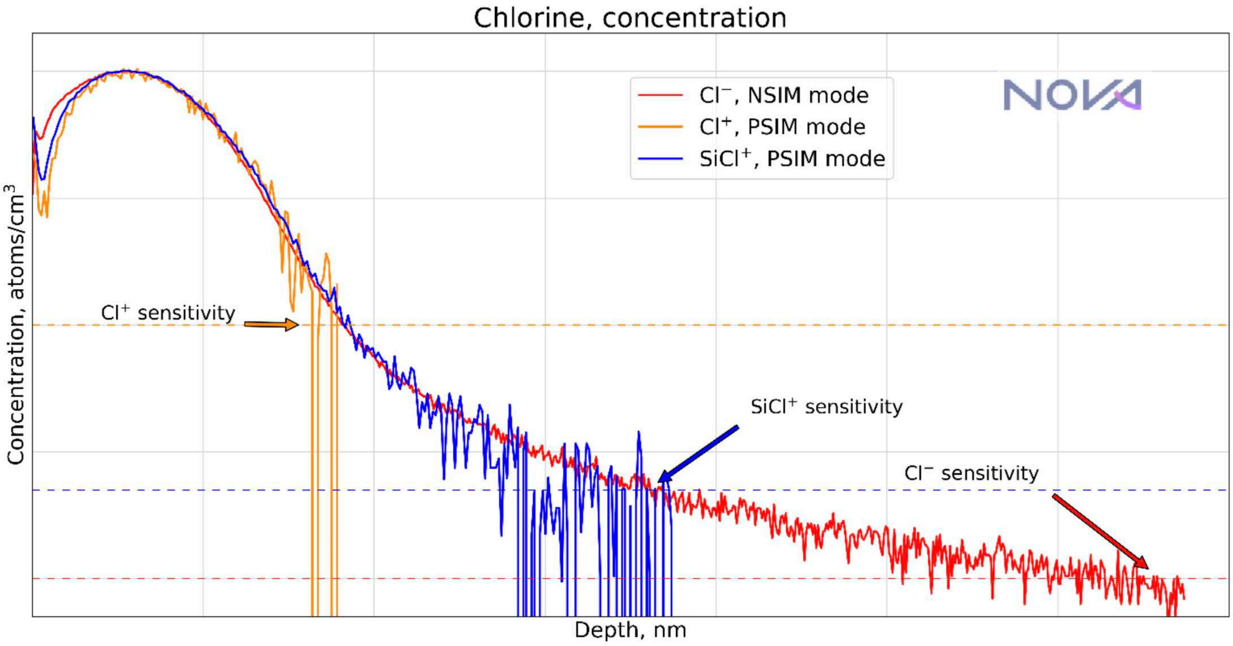

Figure 2. Chlorine implant in Silicon profile of concentration (atoms/cm3) as a function of depth (nm). Measurements in PSIM and NSIM mode provide consistent information, including proxy species of SiCl+.

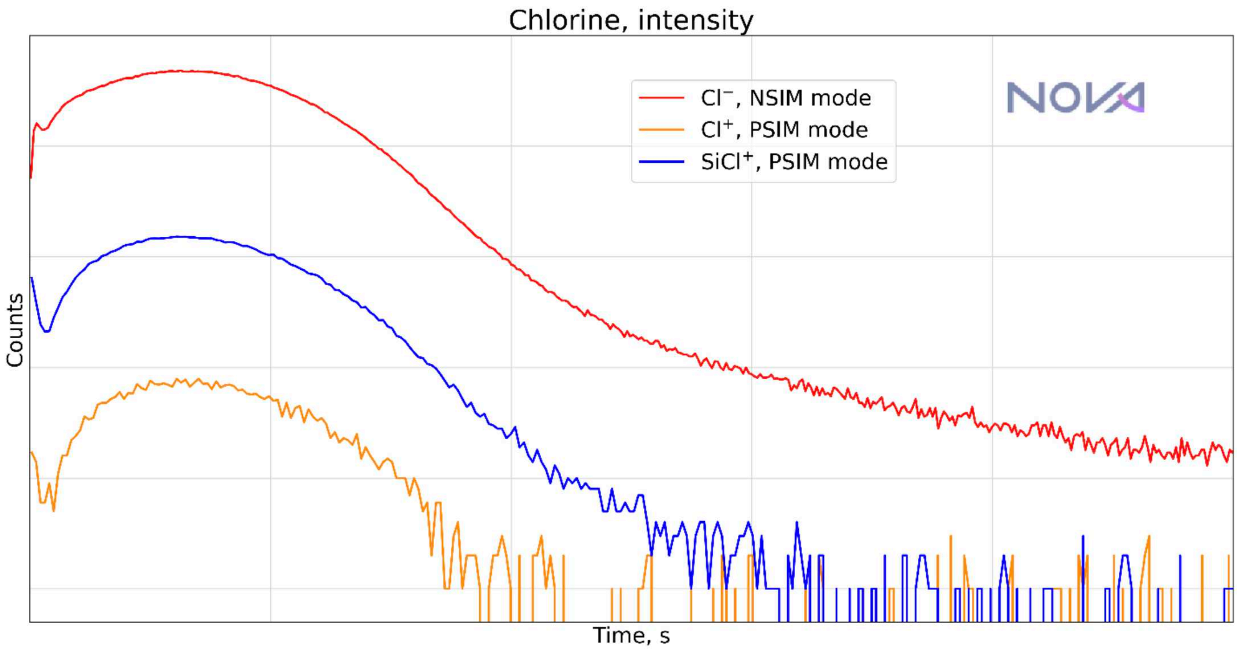

Figure 3. Comparison of sensitivity to Chlorine and SiCl+ as proxy to Chlorine in negative and positive ion modes.

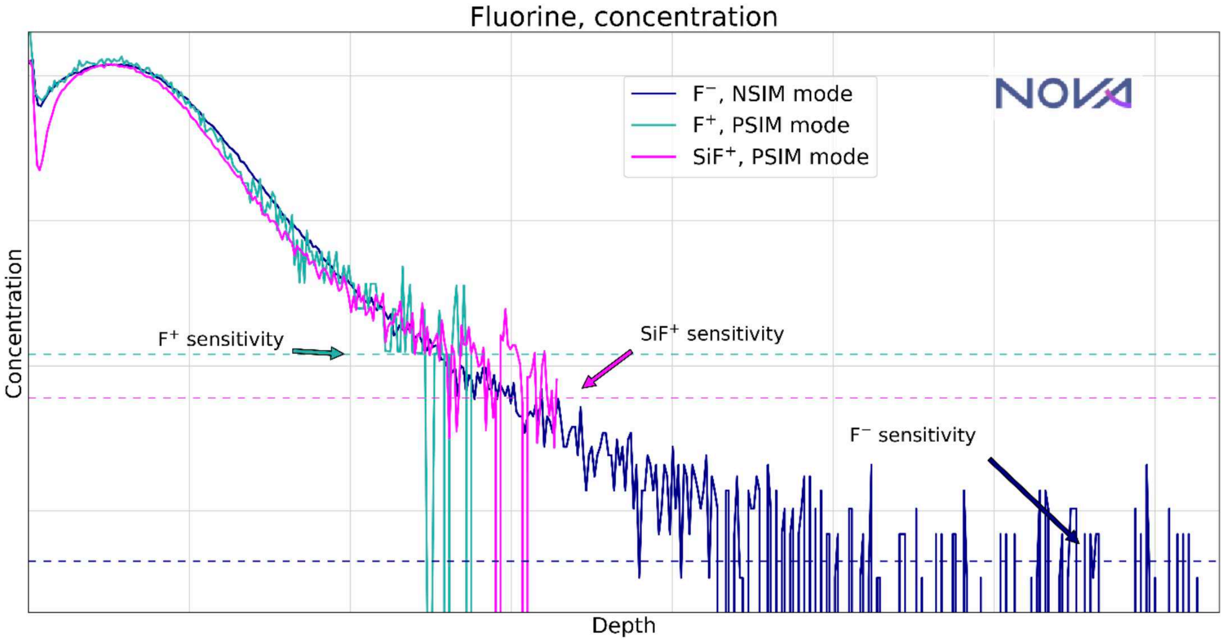

Figure 5. Fluorine implant in Silicon profile of concentration (atoms/cm3) as a function of depth (nm). Measurements in PSIM and NSIM mode provide consistent information, including proxy species of SiF+.

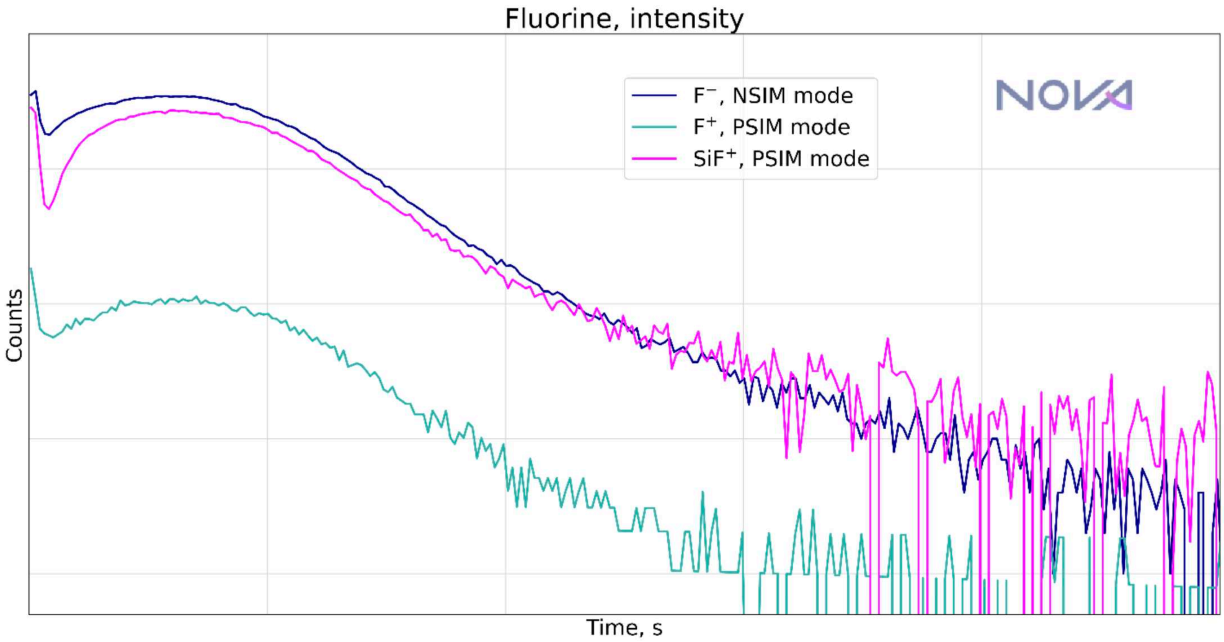

Figure 6. Comparison of sensitivity to Fluorine and SiF+ as proxy to Fluorine in negative and positive ion modes.

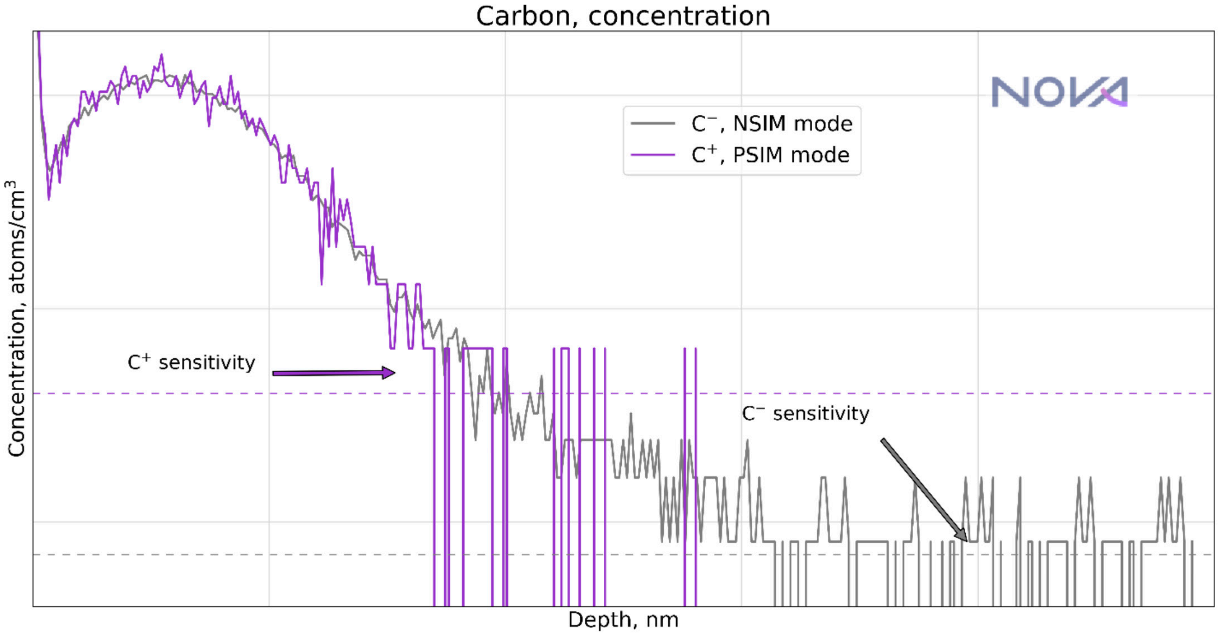

Figure 7. Carbon implant in Silicon profile of concentration (atoms/cm3) as a function of depth (nm). Measurements in PSIM and NSIM mode provide consistent information.

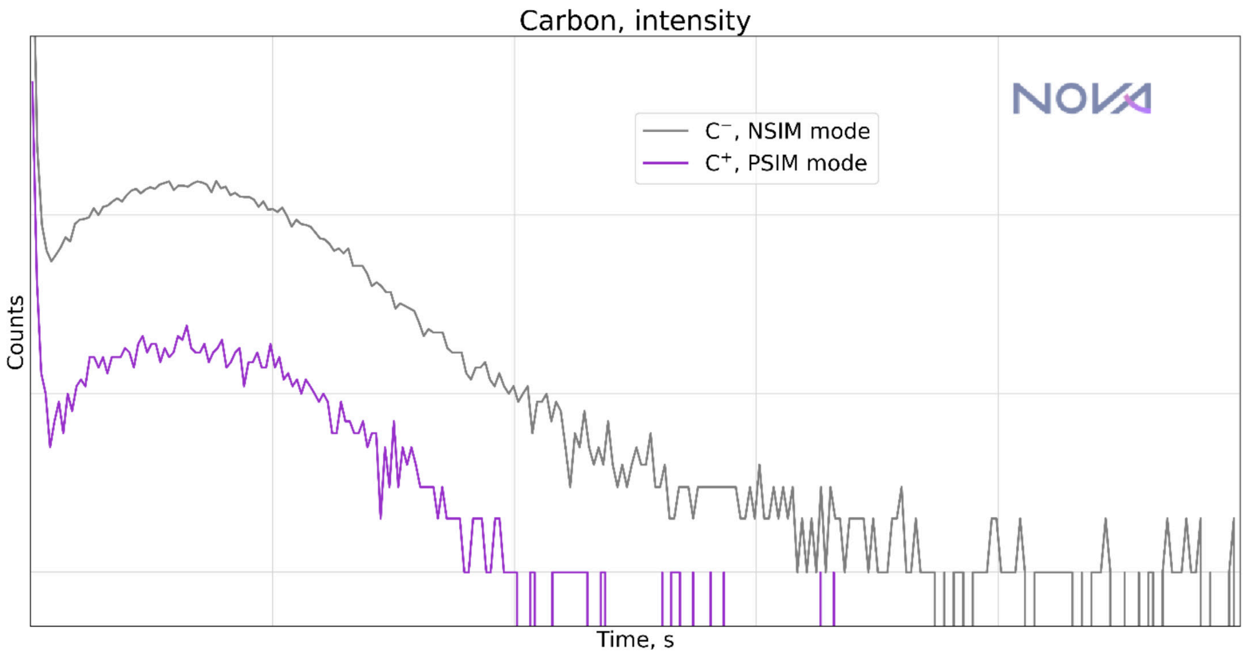

Figure 8. Comparison of sensitivity to Carbon in negative and positive ion modes.

Summary

Nova's METRION® system is an innovative SIMS platform designed for the Fab environment, seamlessly integrating into an automated factory workflow. The system is engineered to deliver wafer-based, high precision metrology results for process control in logic and memory devices. It is capable of measurement of contaminants in Positive Secondary Ion Mode (PSIM) and Negative Secondary Ion Mode (NSIM). The switch between PSIM and NSIM modes is controlled within a recipe. The Oxygen primary ion beam provides contamination-free measurement. With automated capability of measuring predefined points across the whole wafer, contaminant distribution across the wafer is generated in the form of an element concentration map.

References

[1] Wu, B.J., Bai, H., Lin, I.K. and Liu, S.S., "Al-Cu Pattern Wafer Study on Metal Corrosion Due to Chloride Ion Contaminants", IEEE Trans. Semicond. Manuf. 2010, 23: 553–558.