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An ITW Company

TECHNICAL NOTE

PWP Improvement Using an In-tool Ionization System

A key to improving fab yields has always been to reduce contamination on wafers. Controlling particle contamination is increasingly difficult as device feature sizes shrink, and killer particle sizes shrink correspondingly. Gravity and airflow determine whether large particles are deposited on a wafer; for smaller particles (less than 500 nm) electrostatic attraction is the determining factor. Electric fields from charge on a wafer or on adjacent tool surfaces are significant contributors to particle deposition. Air ionization is the only effective method for neutralizing static charge from insulative wafers and tool surfaces.

To determine the effect that ionization has on reducing particles per wafer pass (PWP), a wide-ranging experiment was undertaken at a large 300 mm production fab. This paper presents the results of this experiment for four different process tools that were tested using the fab's normal daily tool qualification process (which included scanning a monitor wafer to count particles, running the wafer through the process, scanning the wafer again to count particles, and then determining particle adders and subtractors). Data for several months prior to installation of an ionization system was compared to data taken after the ionization system was installed and calibrated.

The results of the experiment show that a properly designed and operating ionization system provides a statistically significant reduction in PWP, ranging from 40% to 92% improvement.
The graph below summarizes the results for each of the four tools. In each case, it can be seen that significantly fewer particles are deposited on the wafer when ionization is used.

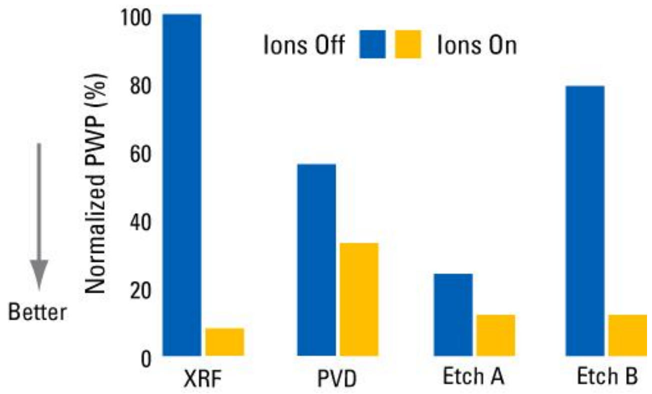

Figure 1. A summary of four tools showing the effect of ionization on the average PWP

Electrostatic Attraction and Wafer Processing

Wafers can become charged two main ways:

1. **Tribocharging**: the contact and separation of dissimilar materials. Examples of tribocharging include when a wafer is handled by a robot end effector with ceramic or Teflon™ pads, when a wafer is placed on and then removed from a pre-aligner or chuck, when liquids are deposited on a wafer a nd then spun off (most wet clean processes), or through polishing operations (CMP).

2. **Process Activity**: acquiring electrostatic charge from various processes themselves, including ion implant, many plasma processes, or e-beam metrology. In all of these cases, a flow of strongly ionized gases or charged matter impacts the wafer, transferring its charge.

Once a wafer has acquired a charge, the charge can be difficult to remove. Wafers, through normal processing, form an insulative oxide layer on the bottom and edges, which is where they are normally gripped and have contact to electrical ground. This makes the wafer an isolated conductor, unable to discharge through the insulative oxide layer. In such cases, even when placed onto the dissipative fingers in a properly grounded FOUP, the wafer will hold charge. Intermediate process layers on the top surface of the wafer may also be insulative, trapping charge. Once a wafer has a charge on its surface, particles with the opposite polarity are strongly attracted and are deposited. The standard rules for equipment design—ground all conductive surfaces and use conductive or dissipative materials wherever possible—do not solve these problems. Only the use of air ionization can remove such surface charges. Regardless of how the charge gets on the wafer, until it is neutralized or dissipated, the charge on the wafer will continue to attract any particles in the air with an opposite polarity.

Experiment Design

As part of a fab-wide contamination control improvement program, a leading device manufacturer operating a production 300 mm fab looked for ways to improve yield through micro-contamination control. This manufacturer runs process monitor wafers for many of their process steps daily in the following sequence:

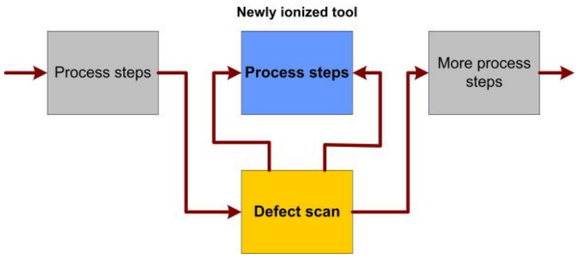

Figure 2. The process step sequence

This PWP measurement serves as one of the device maker's standard qualification steps for each of these process tools. It was determined that this measurement serves as a valid comparison metric for determining the effect of ionization before and after installation, providing the process recipe itself does not change over the course of the experiment. The steps of the experiment consist of:

1. Performing defect scans using a KLA-Tencor SP1, set to measure particles at >100 to 160 nm (the exact threshold varying depending on the process step). Particles are counted, locations noted, and binned.

2. Running the monitor wafer through the process (or as similar a process as possible when running the actual process is impractical).

3. Running the monitor wafer through the same SP1 again. Sophisticated software analyzes the defect map and compares it to the "before" map to adjust for particles that "bin" differently (e.g., a particle is measured as 0.19 µm in the first pass, and 0.21 µm in the second pass). This results in an accurate distribution of particles added to the wafer by that process tool.

4. Collecting the number of particle adders per monitor wafer over a period of several months, including time before and after the ionization

system is installed and qualified. The data is analyzed using standard statistical techniques and evaluated for statistical significance.

Four process tools all recently retrofitted with ionization systems were chosen for this experiment. No changes were made to the tool process recipe during the test period. The tools consisted of two four-chamber etch tools, an XRF tool, and a PVD tool. All of the tools in the study were from well-known tool vendors and followed good design practices for minimizing electrostatic charge. The only change to the tools during the experiment was the installation of an ionization system in each tool's EFEM (Equipment Front End Module). All four tools had been in production for several months before the experiment, providing a stable PWP baseline.

The ionization system for each tool was configured and adjusted to meet the fab's specifications (a typical set of specifications is shown in Table 1). Each tool, due to different EFEM designs, airflow, wafer residence time, wafer travel path, and construction required different ionization configurations and settings.

Typical specifications	Permitted value
Interior tool surfaces within 300 mm of a wafer at any time during its residence in a tool	<100V/in
Maximum decay time (measured as specified in ANSI ESD STM 3.1)	<15 seconds
Maximum swing voltage	<150V
Ionizer cleanliness	Single-crystal silicon emitter points; exceeds Fed. Std. 209(e) Class 1

Table 1. Typical fab specifications for ionization

Experiment Results

A statistical analysis of particle adders was done for each tool. Results for each tool are shown in the form of a histogram graph showing particle adders as well as a table of statistics. Each graph plots the percentage of wafers in the study vs. number of particle adders.

XRF Tool Results

The X-Ray Fluorescence (XRF) tool shows a typical particle distribution for ions off: approximately 42% of wafers have 0-10 adders, approximately 22% from 10-20 adders, and shown on the right side of the graph, approximately 10% with 80+ particle adders.

Adding ionization substantially shortens or eliminates the right-hand tail; none of the wafers showed more than 20-29 particle adders.

Statistic	Ions on	Ions off
Mean	40.6	3.3
Standard error	27.9	2.2
% improvement		92%

Table 2. XRF tool statistics

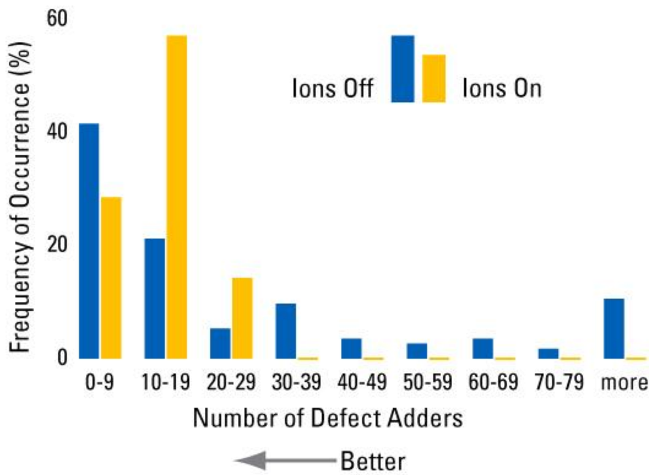

Figure 3. XRF tool results showing the number of particles before ionization and after ionization

PVD Tool Results

The PVD tool again shows that the number of defect adders without ionization is higher than with ionization, and that the spread in defect adders are much greater. In this case, all wafers with ionization on are in the 0 particles added to +59 particles added per wafer, while wafers without ionization range from 0 particles added to >120 particles added.

Statistic	Ions off	Ions on
Mean	22.7	13.6
Standard error	4.1	1.5
% improvement	40%	

Table 3. PVD tool statistics

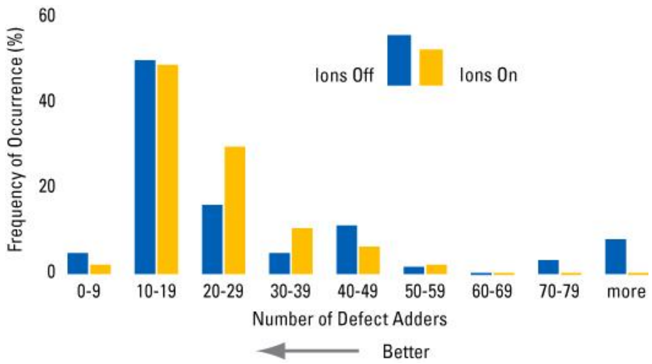

Figure 4. PVD tool results showing the number of particles before ionization and after ionization

Etch A Tool Results

The Etch A tool again shows that the numbers without ionization are higher than those with ionization, and the spread in results is much wider. In this case, all wafers with ionization on are in the 0 particles added to +49 particles added per wafer, while those without ionization range from 0 particles added to 200+ particles added.

Statistic	Ions off	Ions on
Mean	10.0	4.8
Standard error	3.0	1.9
% improvement	52%	

Table 5. Etch A tool statistics

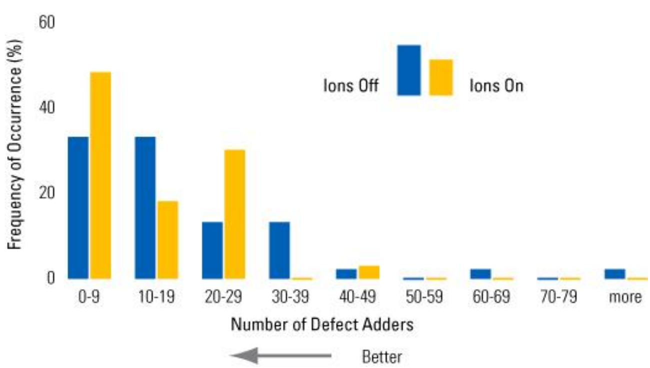

Figure 5. Etch A tool results showing the number of particles before ionization and after ionization

Etch B Tool Results

The Etch B tool results show that the numbers without ionization are higher than those with ionization on, and the spread in results is much wider. In this case, all wafers with ionization on are in the 0 particles added to +69 particles added per wafer, while those without ionization range from 0 particles added to 200+ particles added.

Statistic	Ions off	Ions on
Mean	32.2	5.0
Standard error	8.2	1.7
% improvement	84%	

Table 6. Etch B tool statistics.

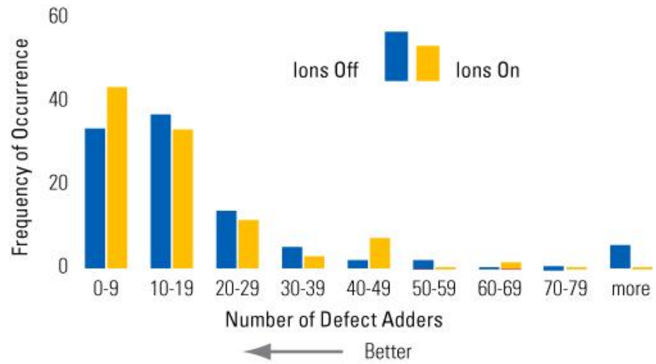

Figure 6. Etch B tool results showing the number of particles before ionization and after ionization

Summary

Experiments with four different process tools each generated a significant improvement in PWP when an appropriately designed and installed ionization system was operational.

Figure 1 summarizes the results of these four tools. The results are normalized, with the XRF tool "ions off" PWP results being defined as "100." Each tool is represented by a blue bar showing the mean number of defect adders with "ions off," and a red bar showing the mean number of defect adders with "ions on." For example, the XRF tool shows "ions off" at 100 and "ions on" at 8, meaning the "ions on" wafers had on average only 8% of the defect adders that "ions off" wafers had on average. This is a 92% improvement in PWP.

The PVD tool in Figure 1 has an "ions off" PWP level approximately 56% of the XRF tool benchmark, which improves to approximately 40% when ionization is on, a 40% improvement in PWP.

The Etch A tool shows the best "ions off" performance of the four tools studied, with a PWP level of 24% that of the XRF tool benchmark. However, "ions on" still lowers the average PWP down to 12%, which is a 52% improvement.

The Etch B tool shows a similar dramatic improvement with ionization, going from approximately 79% of the XRF tool benchmark with no ionization to 12% with "ions on," an 84% improvement.

The histograms for each of the tools (Figures 3, 4, 5, and 6) show the distribution of defect adders for all of the wafers measured. In each case, there are many wafers with relatively few adders and just a few wafers (typically <10%) with large numbers of adders. It is the number of wafers with a large number of defect adders in the "ions off" data that is most striking. The presence of occasional high count wafers causes the distribution of defect adders to have a right-hand "tail" on the graph, or "skew." This difference can be quantified by looking at the skew statistic. A symmetrical distribution (such as the XRF "ions on" data) has a skew of zero; the more the data tails off to the right, the higher the value of skew. The skew values for each of the four tools are presented in Figure 7.

The incidence of high count wafers was greatly reduced by the addition of ionization. This suggests that there is a change in the physical mechanism for contamination of the wafers. If there is a change in the mechanism for deposition of contaminating particles on the surface of the wafer with "ions off" vs. "ions on," it is expected that the distributions will have greatly different skew values. In each case, the skew is substantially greater for the case of "ions off," indicating the physical process of deposition of contamination on the wafers has been substantially modified for the better by the addition of air ionization.

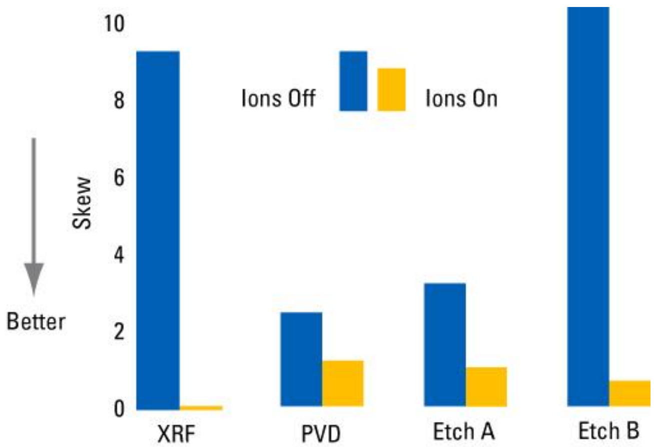

Figure 7. A summary of the effect of ionization on PWP

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