MARCH 2007

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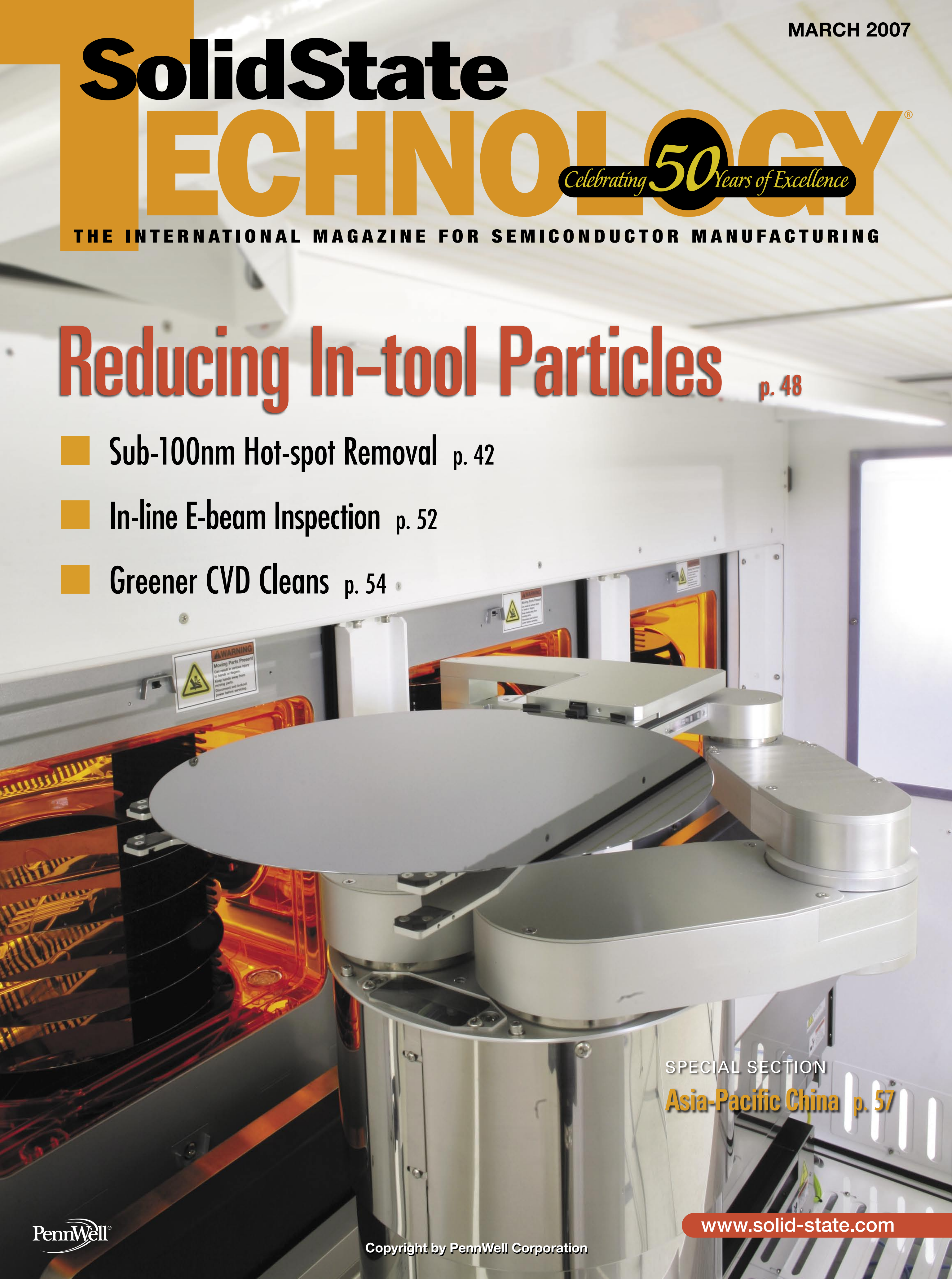

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Improving particle contamination control with

in-tool air ionization

EXECUTIVE OVERVIEW The advent of nanoscale feature sizes in semiconductor devices has created a greater sensitivity to contamination by nanoscale particles. At large particle sizes, gravity and airflow determine the particle deposition rate in a given process tool. For particles smaller than 500nm, electrostatic attraction is the determining factor for surfaces with typical fab level surface charges. In-tool air ionization can neutralize the static charge on the insulating surfaces of the process tools and the wafers. Air ionization in manufacturing process tools greatly reduces the incidence of high particle counts.

Feature sizes of state-of-the-art production semiconductor devices are now in the 65nm regime, and this has produced a corresponding reduction in the size of “killer” defects that destroy device functionality and critically degrade process yield. The *International Technology Roadmap for Semiconductors* (*ITRS*) stipulates that critical particle diameters are approximately 36nm in 2006, reducing to less than 20nm after 2010 [1]. Controlling particle contamination at these dimensions involves the consideration of particle adhesion mechanisms heretofore of only limited importance.

Gravity and airflow determine whether larger particles are deposited on a wafer; for smaller particles (less than 500nm) field-driven interactions are the most important factors. Until recently, countermeasures that can prevent field-induced particle deposition have not been as well developed as the laminar air flow protections of a modern cleanroom. A seminal paper by Bowling in 1985 [2] delineated field-induced forces as “long-range attractive interactions which act to bring the particle to the surface and establish the adhesive contact area. These include van der Waals forces, electrostatic forces (and magnetic attractions). Electrostatic attractions include both bulk excess charge image forces and electrostatic contact potentials.”

Once a wafer has acquired a charge, any such change is difficult to remove. The standard rules for equipment design—ground all conductive surfaces and use conductive or dissipative materials wherever possible—are not effective in removing the charge from a wafer inside the equipment. Through normal processing, wafers acquire an insulating layer of oxide on the backside and wafer edge, those areas where they are normally contacted and gripped. Consequently, each wafer is an isolated conductor that cannot be discharged through dissipative contacts to these areas (i.e., in a properly grounded FOUP). Until a charge is neutralized or dissipated, the electrical field that the charge creates will continue to attract any particles in the air having an opposite polarity. Only the use of air ionization can effectively remove surface charges.

This article describes the implementation of a commercial in-tool ionization system in four different 300mm wafer processing tools operating under normal process qualification conditions. Particles per wafer pass (PWP) data were collected for each of these tools both with and without air ionization over a period of months, and were subjected to statistical analyses to determine whether significant reductions in PWP could be traced to the use of air ionization.

In-tool ionization test methodology

This study was performed as part of a fab-wide improvement program for contamination control in a high volume 300mm line of a leading device manufacturer. The PWP value serves as the fab’s standard qualification metric for process tools. The metric is valid for tool-to-tool comparisons provided that process recipes do not change or experience systematic drift in conditions over the duration of the testing period. Four process tools that had been recently retrofitted with ionization systems in their equipment front end module (EFEM) were examined: two four-chamber etch tools, an XRF metrology tool, and a PVD tool.

Due to different EFEM designs, airflow, wafer residence time, wafer travel path and construction, each tool required different

Table 1. Typical fab specs for ionization

Typical specification	Permitted value
Interior tool surfaces within 300mm of wafer at any time during its residence	<100V/in
Maximum decay time (measured as specified in ANSI ESD STM 3.1 [10])	<15 sec
Maximum swing voltage	<150V
Ionizer cleanliness	Single-crystal silicon emitter points; exceeds Fed. Std. 209(e) Class 1

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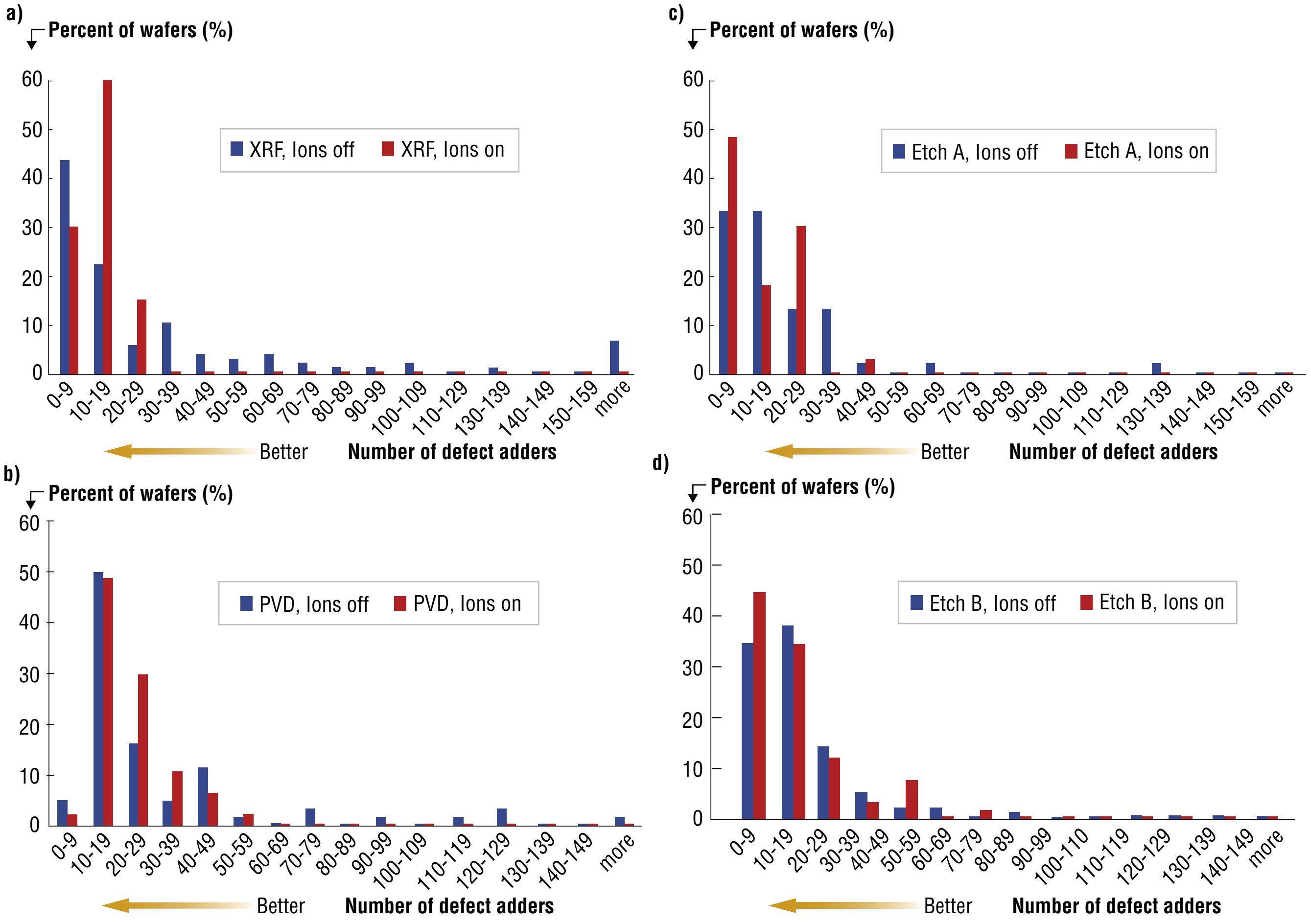

Figure 1. Particles per wafer pass (PWP) before and after the installation of an in-tool ionization system for **a)** XRF, **b)** PVD, **c)** etch Tool A, and **d)** etch Tool B 300mm wafer processing tools.

ionization configurations and settings to meet existing fab specifications (**Table 1**) [3]. The selected tools were representative of vendors commonly used in the given applications and had designs that followed best practice for electrostatic charge minimization. All of the tools had been proven stable in production for several months prior to this study.

A KLA-Tencor SP-1 Surfscan system—with threshold values set in the 100–160nm range, depending on the process step—was used to scan monitor wafers before and after processing to accurately determine the particles added. We collected data over a period of several months, inclusive of the time before and after the installation of the ionization system. We analyzed the cumulative data using standard statistical techniques and evaluated the data for the statistical significance of the effect of the ionization system on PWP values.

Comparative PWP data

Statistical analyses of the particle adders for each of the four process tools are displayed graphically in **Fig. 1**. Each histogram displays the distribution of particle adders vs. the frequency of occurrence for wafers processed with the ionization system turned off and with it turned on. **Table 2** shows the mean PWP values determined for each tool along with statistics on standard errors of the PWP numbers and on the relative improvement observed when ionization was employed in the EFEM.

The data on particle adders for the XRF tool (**Fig. 1a**) show a typical frequency of occurrence distribution with the ionization system turned off. The majority of wafers show <20 PWP with ~42% of the processed wafers showing <9 PWP and 22% showing 10–19 PWP. More than 20% of the processed monitor wafers experienced ≥40 PWP, with ~7% of the wafers gaining >160 PWP. Using ionization, the PWP frequency distribution data displayed a distinct

Table 2. Cumulative mean PWP data for the four process tools under study

Tool	Ionization on/off	Mean particle count	Standard error	Improvement (%)
XRF	Off	40.6	27.9	
	On	3.3	2.2	92
PVD	Off	22.7	4.1	
	On	13.6	1.5	40
Etch Tool A	Off	10.0	3.0	
	On	4.8	1.9	52
Etch Tool B	Off	32.2	8.2	
	On	5.0	1.7	84

shift to fewer particle adders, with 86% of the processed wafers adding ≤19 particles and none with more than 29 particle adders. The mean PWP values for the tools (Table 2) show that the implementation of ionization produced a large drop in the number of particles added to a monitor wafer during processing.

Particle analysis data for the PVD tool (**Fig. 1b**) show similar trends to that observed with the XRF tool. Without ionization, the number of particle adders experienced on processing through the PVD tool is greater, as is the frequency of wafers with high particle counts. With ionization present, all of the processed wafers added <60 PWP, and the majority (80%) experienced <29 PWP. Without ionization, ~10% of the processed wafers accumulated ≥60 particle during process with a significant number of wafers adding >130 PWP.

Figures 1c and 1d show similar results for the PWP analyses for Etch Tools A and B. With ionization all monitor wafers accumulated <60 particle adders, whereas without ionization ~5% of the wafers added ≥60 particles with a significant number showing as many as 139 PWP.

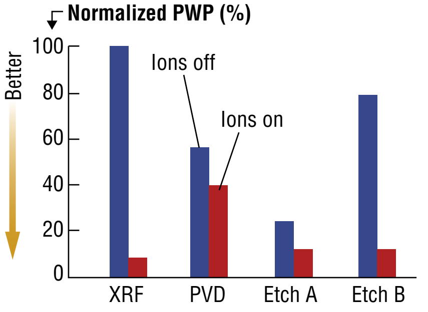

Figure 2. The normalized effect of ionization on the average PWP in each of the four process tools under study.

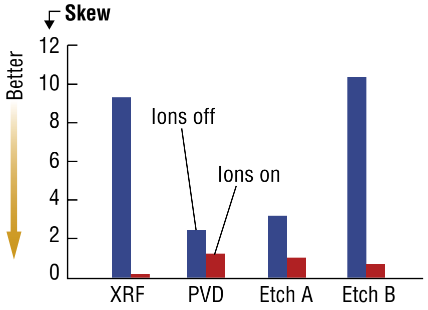

Figure 3. A summary of the skew statistic for the effect of ionization on PWP in all four process tools under study.

Analyses of particle reductions

Figure 2 provides a summary of the normalized PWP data for all four process tools. Normalization of the PWP data was performed by normalizing the XRF "ions off" PWP results to 100 and then determining the PWP values for all other tests by the normalization factor. Each tool is represented by a blue bar showing the mean number of particle adders without ionization and a red bar showing the particle adders with ionization. The results displayed for the XRF tool show that only eight "normalized" particles were added when ionization was present. This constitutes a 92% improvement in the PWP performance of the XRF tool when ionization is used.

The PVD tool showed a relative PWP level of 56% of the normalized XRF tool benchmark, and this improved to 40% of the benchmark with the use of ionization. The difference between the two values constitutes a 30% improvement in PWP performance of the PVD tool when ionization is present in the EFEM.

The data further show that even for tools performing well without ionization, the addition of ionization results in a significant improvement in PWP characteristics. Etch Tool A has the best "ions off" performance of the four tools studied, with a PWP level of just 24% of the XRF benchmark. With ionization, this tool experiences a reduction in PWP to ~12% of the XRF benchmark, an improvement in PWP performance of 52%. Similarly, Etch Tool B exhibits an 84% improvement in PWP performance when ionization is deployed.

The histograms for each of the tools (Fig. 1) show the frequency distribution of particle 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%) gaining a large number of particles during "ions off" processing. These wafers cause the frequency distribution of PWP histograms to exhibit a right-hand "tail" or "skew." The skew statistic for a tool quantifies the negative effect of PWP upon wafer yield. A symmetrical distribution (such as that observed in the XRF "ions on" data) has a skew statistic value of zero. The more the data tails off the right, the higher the value of the skew statistic.

Figure 3 shows the magnitude of the skew statistic for each tool with and without ionization deployed. This figure dramatically illustrates the improvement in PWP performance in these tools when ionization is deployed in the EFEM. In each case, the skew statistic has a much higher value when ionization is not present, indicating that the incidence of high particle count wafers is significantly reduced with ionization turned on. This large difference in the "skew-ness" of the PWP frequency distribution depending on in-tool ionization is consistent with a change in the underlying physical mechanism of particle deposition.

Conclusion

Ionization of the ambient atmosphere inside different process tools produces a significant improvement in particle contamination control within the tool. The PWP data show that when ionization is employed, the frequency of high particle count wafers drops dramatically, as does the average number of particles added to wafers passing through the tool. Analyses of the data show that a properly designed and operating ionization system provides a statistically significant reduction in the PWP metric, ranging in value from 40% to 92% improvement. ■

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