

Wafer backside particle reduction

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Abstract—In semiconductor manufacturing, wafers pass through numerous processing tools—including chemical vapor deposition (CVD), physical vapor deposition (PVD), ion implantation, etch, and lithography systems. As wafers move through multiple process tools, particles originating from wafer-handling components can accumulate on wafer backside surfaces. This contamination becomes increasingly important as device dimensions shrink and process tolerances tighten. Contaminants can also migrate from wafer to wafer, ultimately transporting particles out of the original tool and into downstream equipment that is highly sensitive to even small levels of particulate contamination [1].

Several methods are currently used to clean wafer-handling components such as electrostatic chucks, including standard wafer cycling [1], specialized chuck-cleaning wafers, in-situ electrostatic cleaning, and plasma-based cleaning approaches [2-4]. In this work, we propose an alternative method that uses pulsed backside gas (BSG) purge between the low-contact electrostatic chuck and a standard silicon wafer to dislodge and remove particles from the chuck surface. This technique leverages a fast three-way valve to rapidly cycle backside pressure.

Keywords—Backside particles, electrostatic chuck, gettering, ion implantation, particle contamination, wafer cleaning.

I. INTRODUCTION

Backside particle contamination remains a significant challenge in semiconductor manufacturing [1]. Particles trapped between a wafer and an electrostatic chuck (ESC) can degrade wafer flatness, heat-transfer uniformity, overlay accuracy, and device yield [5]. During wafer handling and electrostatic clamping, particles are generated by abrasion and accumulate on wafer-support hardware. Additional wafer manipulations result in subsequent transfer to wafer backside surfaces.

Several approaches have been developed to mitigate particle contamination on ESC surfaces. Plasma-assisted cleaning methods remove particles through plasma processing using gas flow [2-4,6], while the sacrificial wafer [3,7] or

chuck-cleaning wafer (CCW) approaches rely on particle transfer to specially designed collection surfaces. These techniques, although effective, often require dedicated cleaning cycles and substantial wafer consumption following preventive maintenance. In manufacturing environments, hundreds of wafer cycles may be required before backside particle levels return to specification, resulting in increased consumable costs, extended recovery times, and reduced equipment productivity.

In this work, a pulsed backside gas (BSG) purge cleaning technique is investigated as an alternative approach for ESC conditioning. The method employs cyclic pressurization and venting of the wafer-chuck interface to generate pressure transients that mechanically dislodge particles. Removed particles are either evacuated through the vacuum system or transferred to the wafer backside, where they may be captured through conventional gettering mechanisms. Process parameters, including backside gas pressure, pulse duration, and plasma electron flood (PEF) operation, were evaluated experimentally on a high-current ion implanter end station. The proposed technique is compared with conventional wafer cycling [1] and is shown to significantly reduce the number of wafers required to restore particle specifications.

II. MATERIALS AND METHODS

All preliminary testing was conducted using a 300 mm low-contact electrostatic chuck (ESC) installed in the end station of a high-current ion implantation test stand. The chuck assembly included gas distribution channels beneath the wafer for cooling, electrostatic clamping electrodes, a chuck controller, and a pressure-regulated gas delivery system. Nitrogen (99.999% pure) was selected as process gas. A clamping voltage of 900 V was applied throughout the evaluation.

Wafer backside particle measurements were performed using a KLA Surfscan SP5 wafer inspection system. The instrument utilizes laser light scattering to detect and classify particles and surface defects on silicon wafer surfaces. Process performance was quantified in terms of backside particle

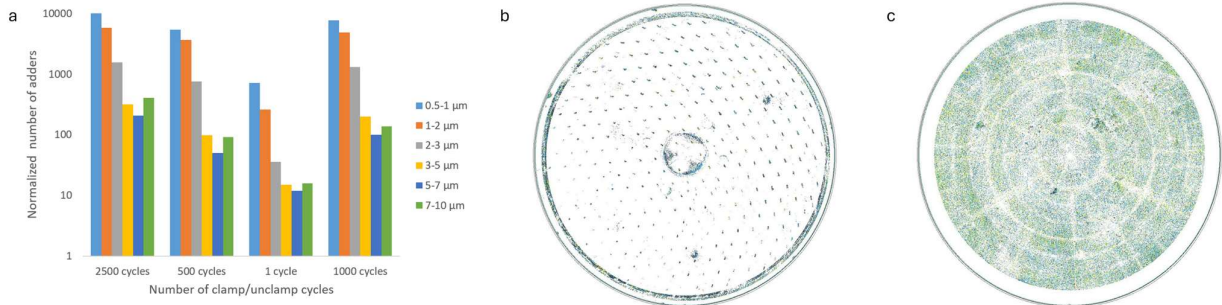


Figure 1. (a) Normalized particle adds by particle-size range as a function of electrostatic chuck clamp/unclamp cycles, representative wafer backside particle distribution map for 1000 clamp/unclamp cycles (b), and wafer backside particle distribution following ESC contamination with dry wipes (c).

adders above the selected inspection threshold size. In addition, Vapor Phase Decomposition (VPD) Inductively Coupled Plasma Mass Spectrometry (ICP-MS, PerkinElmer) trace metal contamination analysis was conducted using 300 mm silicon wafers to compare the effectiveness of conventional wafer cycling and backside gas purging on an Axcelis Purion XE-series high-energy ion implanter.

To establish a reproducible source of backside particle contamination, the electrostatic chuck (ESC) was initially evaluated using repeated wafer clamp/unclamp cycles. Backside particle adders increased with the number of clamp/unclamp cycles, see Fig. 1(a). The particles so generated were highly localized; the wafer backside exhibited a distinct imprint of the chuck surface, with particle accumulation concentrated at contact features including the mesas, lip seal, and grounding pins, Fig. 1(b). A significant fraction of these particles (more than 90 %) was removed upon wafer replacement, making this approach unsuitable for generating a stable and representative contamination condition.

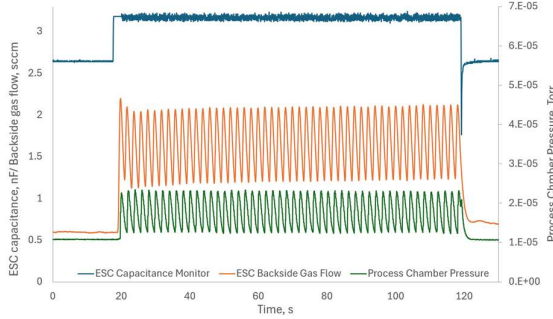


Figure 2. Backside gas purge routine: ESC capacitance, backside gas flow rate, and process chamber pressure as a function of time.

A different contamination method was therefore adopted for evaluating the cleaning process. The chuck surface was intentionally contaminated using dry cleanroom wipes (TX 609), producing a more uniform and reproducible contamination layer, Fig. 1(c). This procedure consistently generated more than 200,000 backside particle adders on the

first wafer processed after contamination. Similar results were observed in three independent contamination-cleaning cycles. Pressure cycling was then implemented using a fast three-way gas valve that alternates between pressurizing the wafer-chuck

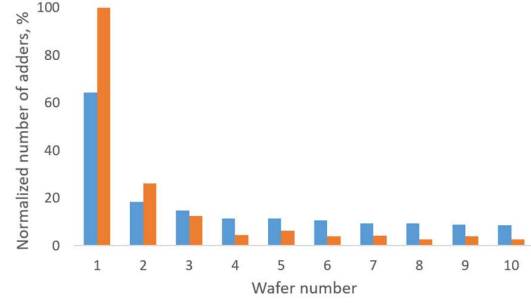


Figure 3. Comparison of normalized particle adders ($\geq 0.5 \mu\text{m}$) measured on ten consecutive wafers following processing with the gettering (blue) and backside gas (BSG) purge routines (orange).

interface and venting this interface to the vacuum environment. The resulting periodic pressure excursions beneath the electrostatically clamped wafer produce synchronized oscillations in chamber pressure, while the monitored ESC capacitance remains constant confirming stable electrostatic clamping during the purge process, see Fig.2.

III. RESULTS AND DISCUSSION

Starting from the intentionally contaminated electrostatic chuck, contaminant particle transfer was followed on ten consecutive wafers employing either gettering without or gettering with the backside gas (BSG) purge routine. Contamination transfer was monitored and compared using a normalized particle adders ($\geq 0.5 \mu\text{m}$) protocol. The BSG purge condition exhibits a higher initial particle count on the first wafer but substantially lower particle adders on subsequent wafers compared to the standard gettering procedure, indicating more effective particle removal, see Fig.3. This observation indicates that the purge process

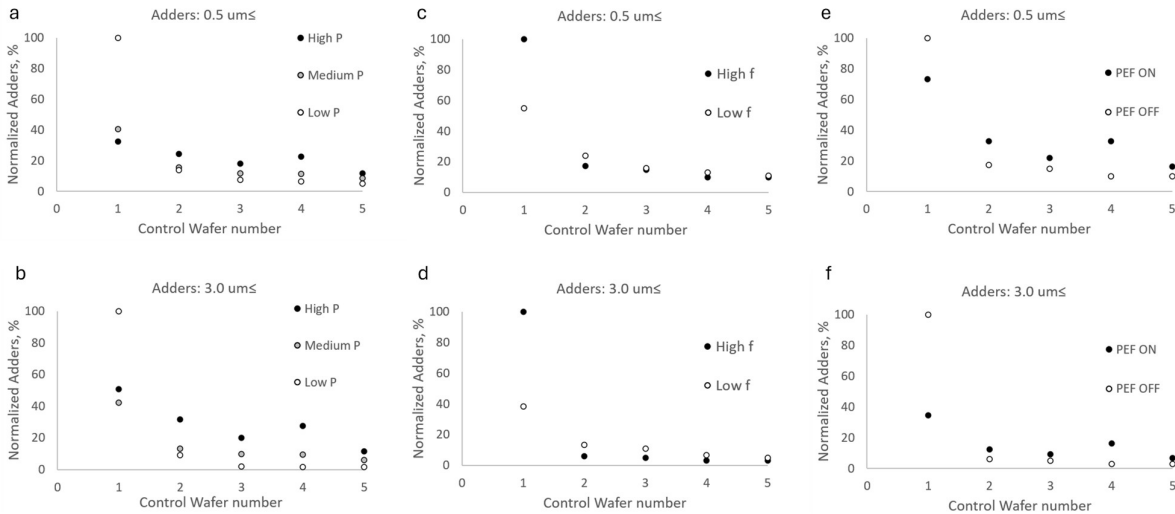


Figure 4. Effect of process pressure (a,b), backside gas flow frequency (c,d), and plasma electron flood (PEF) operation (e,f) on normalized particle adders measured on sequential control wafers. Panels (a), (c), and (e) show particles $\geq 0.5 \mu\text{m}$, while panels (b), (d), and (f) show particles $\geq 3.0 \mu\text{m}$.

rapidly mobilizes accumulated contamination, resulting in enhanced particle transfer to the initial getter wafer and accelerated cleaning of the electrostatic chuck surface.

Optimization of the BSG purge routine showed that more effective particle removal was obtained at lower backside gas pressures, see Fig. 4(a, b). While elevated particle counts were observed during the initial cleaning cycle, subsequent wafers exhibited substantially lower particle adds compared to those processed at higher backside gas pressures. The three-way valve pulse frequency also influenced cleaning effectiveness. Comparison of high and low-frequency flow modulation, see Fig. 4(c, d) showed improved particle removal at higher frequencies. In all cases, particle adds decreased with the wafer number, indicating a progressive conditioning and removal of loose particles from the electrostatic chuck surface. During optimization experiments, under otherwise identical operating conditions, improved particle removal was observed when the plasma electron flood (PEF) source was disabled, see Fig. 4(e, f). This result suggests that local electrostatic conditions influence particle adhesion and transport beneath the wafer during the purge process.

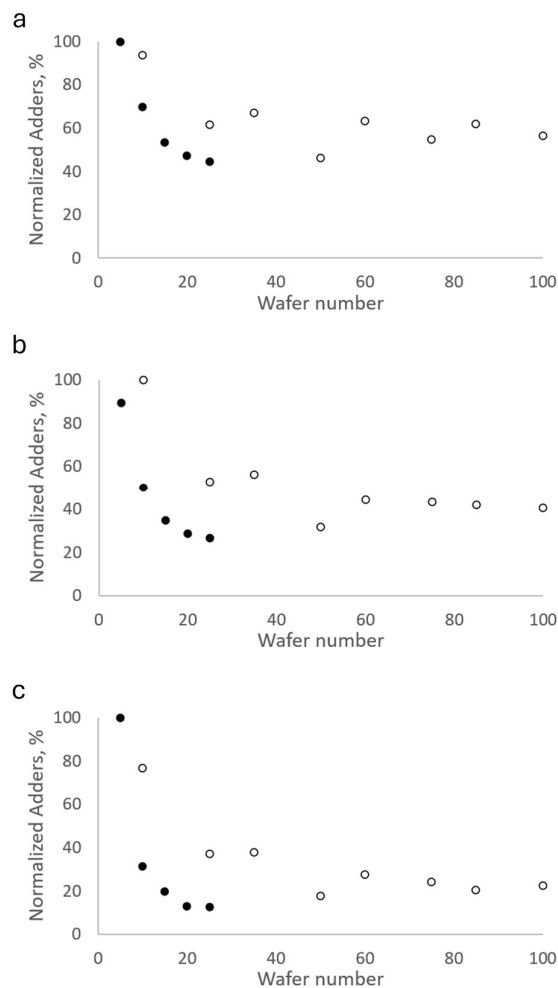


Figure 5. Comparison of normalized particle adds obtained using the conventional gettering process and the gettering process with backside gas (BSG) purge routine as a function of wafer number for particles $\geq 0.16 \mu\text{m}$ (a), $\geq 0.5 \mu\text{m}$ (b), and $\geq 3.0 \mu\text{m}$ (c). Closed symbols: gettering with BSG purge, open symbols: gettering only.

While the cleaning mechanism is not fully understood, the data obtained indicate that particles originating from the electrostatic chuck are physically dislodged and transferred either to the vacuum chamber or to the wafer backside surface with a higher efficiency compared to the absence of pressure and dielectric cycling. No redistribution seems to take place as the adds show an exponential decay over a wide range of particle sizes.

The combined particle and metals data (see below) suggest that cleaning occurs through two complementary mechanisms. During pressurization, backside gas dislodged particles from the chuck surface that are not in contact with getter wafer. During venting, reverse gas flow promotes evacuation of loosened particles toward the pumping system and transfer to getter wafers. Repeated pressure cycling therefore accelerates removal of contaminants that would otherwise require many wafer-clamp cycles to eliminate through conventional conditioning alone. During pressurization, the increased interface pressure is believed to promote particle detachment by overcoming adhesion forces between particles and contacting surfaces. During venting, reverse gas flow induced additional particle transport. Dislodged particles were either evacuated through the exhaust flow or transferred to the wafer backside through particle gettering.

This behavior suggests that lower pressures generate larger pressure gradients during pressurization and venting, thereby increasing transient forces acting on particles trapped at the wafer-chuck interface. Shorter pressurization and venting periods likely allow more effective evacuation of dislodged particles.

The effectiveness of conventional wafer cycling and backside gas purging was tested on an Axcelis Purion XE-series high-energy ion implanter (Fig. 5). Across all measured particle sizes ($\geq 0.16 \mu\text{m}$, $\geq 0.5 \mu\text{m}$, and $\geq 3.0 \mu\text{m}$), the BSG purge process produced a substantially faster decline in particle adds with increasing wafer count (Fig. 5). Conventional gettering would require >100 wafers to approach stable particle levels, whereas the pulsed BSG process achieved comparable or lower particle counts after 20-25 wafers.

To further explore the BSG purge effectiveness, wafer backside metal contamination was analyzed using VPD-ICP-MS. For all elements tested the addition of the BSG method to the standard gettering procedure results in a substantial reduction of metal contaminants, reaching the ICP-MS detection limit for Cr, Cu, Pb, Ni, Ti, W and V (Fig. 6). With

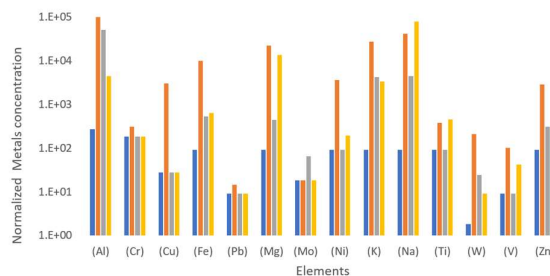


Figure 6. Normalized metallic contamination concentrations (logarithmic scale) for wafer backsides following gettering (orange), gettering with backside gas (BSG) purge (grey), and control wafers (yellow). ICP-MS detection limits for the individual elements are indicated (blue).

the exception of Mo, the BSG method consistently achieves lower metal contamination compared to the standard gettering method and is for Fe, Mg, Ni, Na, Ti and V well below the control wafer values. The metal reduction of the wafer backside covers major contaminants such as Al, Mg, K, Na, and Zn. These findings support the hypothesis that the pulsed BSG process removes particulate material from the interface rather than simply redistributing particles between wafers.

IV. CONCLUSION

A pulsed backside gas cleaning technique has been developed to improve removal of backside particles from electrostatic chuck surfaces. The method employs cyclic pressurization and venting beneath an electrostatically clamped wafer to generate transient pressure gradients that promote particle detachment, transport, and subsequent removal.

Experimental optimization demonstrated improved cleaning performance at lower backside pressure, higher pulse frequencies, and with PEF disabled. Compared with conventional wafer cycling, the proposed technique reduced the number of wafers required to restore particle specifications by a factor of 20. Independent VPD-ICP-MS measurements further confirmed significant reductions in backside metallic contamination, demonstrating that the process removes contamination rather than merely redistributing it.

These results establish pulsed backside gas purging as a practical and cost-effective method for low-contact electrostatic chuck conditioning, reducing wafer consumption, chamber recovery time, and tool downtime following maintenance or venting events. The technique can

be readily implemented using existing backside gas delivery hardware and offers a scalable approach for improving cleanliness in advanced semiconductor manufacturing systems.

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