From Lab to Fab: The Art and Science of Capturing the Uncatchable in CMP Filtration

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INTRODUCTION

As semiconductor nodes advance to A16, A14, and beyond, controlling particle-induced defects during CMP becomes critical. This study consolidates four slurry filtration investigations on flow rate, concentration, shear conditions, and filter design, highlighting the roles of zeta potential, pump type, and filter structure in reducing large particle count (LPC) and defects. APR filters, combining sieving and non-sieving mechanisms, effectively lower LPC and fine particles (<30 nm) while preserving slurry integrity, providing a strategic framework to optimize CMP filtration for yield and reliability.

FILTRATION EFFICIENCY IN CMP SLURRIES: THE IMPACT OF FLOW RATE AND CONCENTRATION

CMP slurries, made of abrasive particles in chemical solutions, are filtered at three stages – bulk, PoT, and PoD – each with different flow and concentration conditions (Figure 1). Bulk filtration runs at higher concentration and flow, while PoD operates lower. Using Entegris NMB-based nanofiber filters (NMB01, NMBA5) with lower shear than traditional microfiber filters, the study tested silica and ceria slurries under varied conditions. Particle retention was tracked over 50 turnovers using an AccuSizer® Fx Nano, focusing on particles >0.5 µm and >0.8 µm.

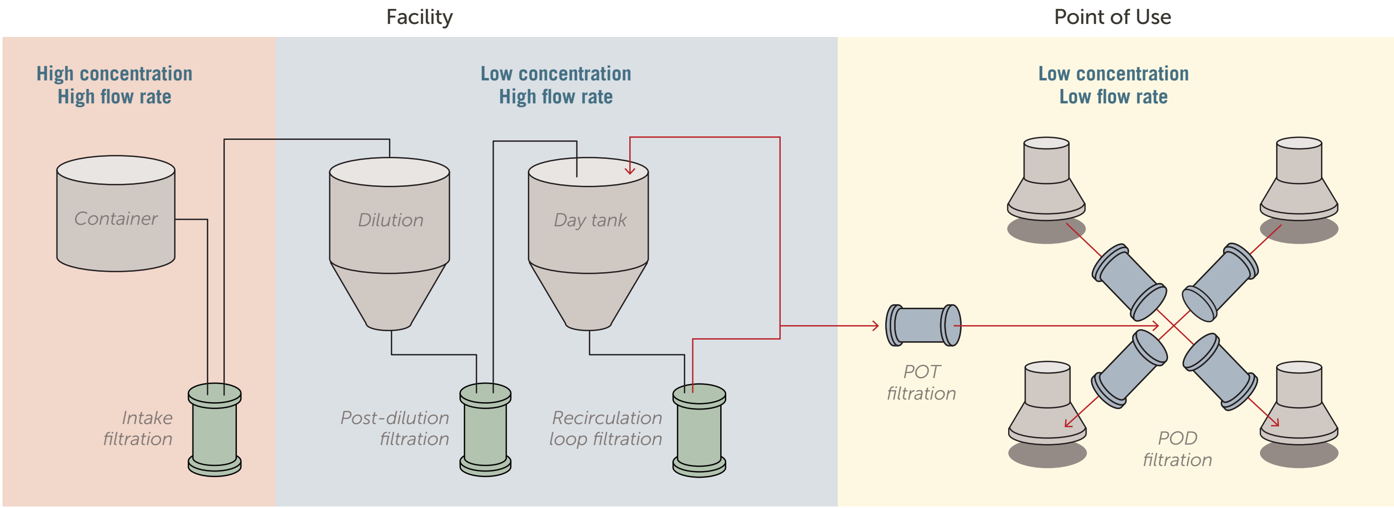


Figure 1. Concentration and flow rate conditions in the slurry delivery system.

Silica Retention Behavior and Electrostatic Effects

Silica slurry filtration showed strong particle retention under high concentration and flow rate, driven by the relatively large zeta potential gap between abrasive and PP filter media. Retention dropped slightly under low concentration and high flow due to particle instability near the isoelectric point. At low concentration and low flow, retention became inconsistent for particles >0.5 µm, likely due to agglomeration and sample instability. However, particles >0.8 µm were consistently retained, confirming nanofiber filters' effectiveness in reducing micro-scratches (Figure 2).

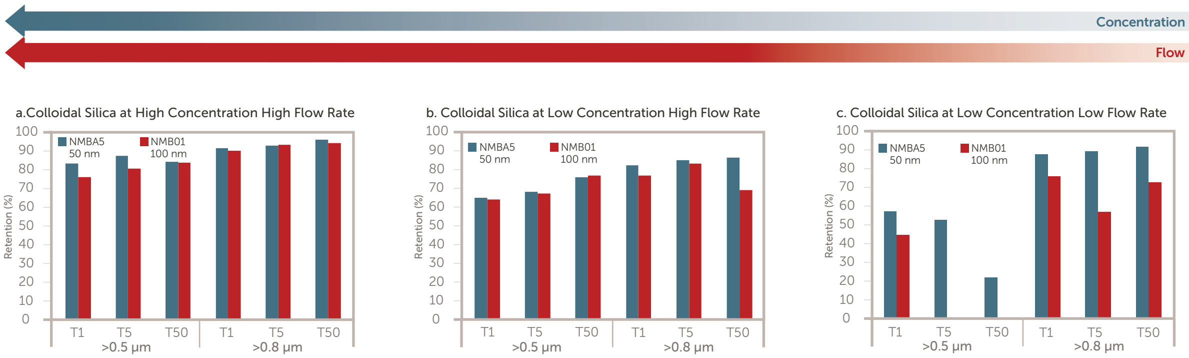


Figure 2. Retention results of colloidal silica abrasive in different test conditions: (a) high concentration, high flow rate; (b) low concentration, high flow rate; (c) low concentration, low flow rate.

Ceria Filtration Performance and Filter Pore Size Impact

Ceria slurry filtration showed more consistent trends. Retention was lower at high concentration and flow due to weaker electrostatic interactions, but improved under low concentration and high flow, likely from enhanced non-sieving effects. The NMBA5 filter, with tighter pores, outperformed NMB01, especially for particles >0.8 µm. At low concentration and low flow, retention stabilized quickly, highlighting the role of lower flux and longer residence time. These results emphasize the combined importance of electrostatic and mechanical sieving mechanisms in filtration performance (Figure 3).

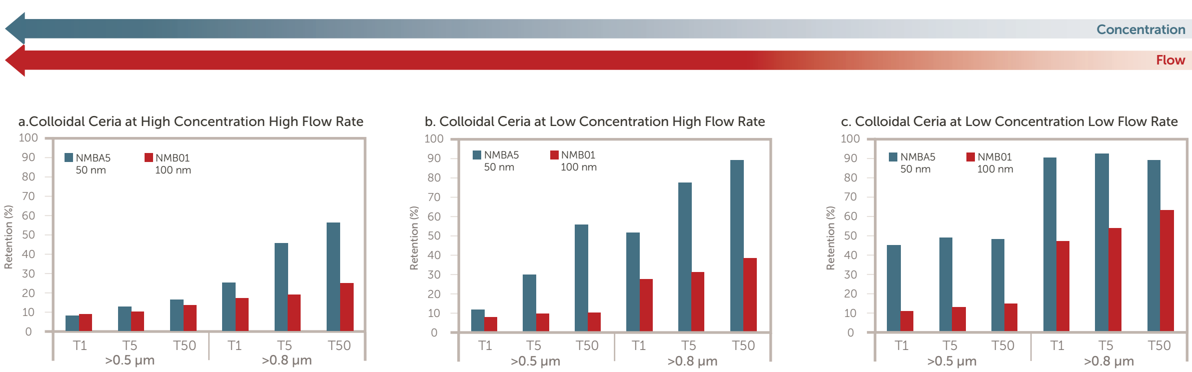


Figure 3. Retention results of colloidal ceria abrasive in different test condition: (a) high concentration, high flow rate; (b) low concentration, high flow rate; (c) low concentration, low flow rate.

UNDERSTANDING SILICA PARTICLE BEHAVIOR AND ITS IMPACT ON CMP DEFECTS

In advanced semiconductor manufacturing, CMP slurry filtration is critical for defect reduction. This study examines how silica particle agglomeration – affected by flow rate, pump type, and filter media – impacts LPC. Colloidal silica proved more shear-sensitive than ceria. Using Entegris NMB filters and comparing peristaltic with magnetically levitated centrifugal (MLC) pumps, filtration was tested at bulk and point-of-use stages with NMB01 and NMBA5 filters.

The study found peristaltic pumps generate much higher shear than MLC pumps, causing greater silica agglomeration and LPC increases – 328% (>0.5 µm) and 190% (>0.8 µm) after 50 turnovers without filtration. NMB filters, especially NMBA5, effectively reduced LPC, while MLC pumps maintained near-baseline levels even unfiltered. Despite LPC growth, overall PSD stayed stable, indicating agglomeration affects only large particles. Lower flow rates with MLC pumps improved retention due to reduced shear and longer residence time. Aging tests showed LPC stability over 3 idle days with nanofiber filters, unlike conventional filters. Polishing tests confirmed NMBA5 cut defect counts by 32% on Cu wafers and 34% on oxide wafers, correlating with a 70–74% LPC reduction (Figure 5).

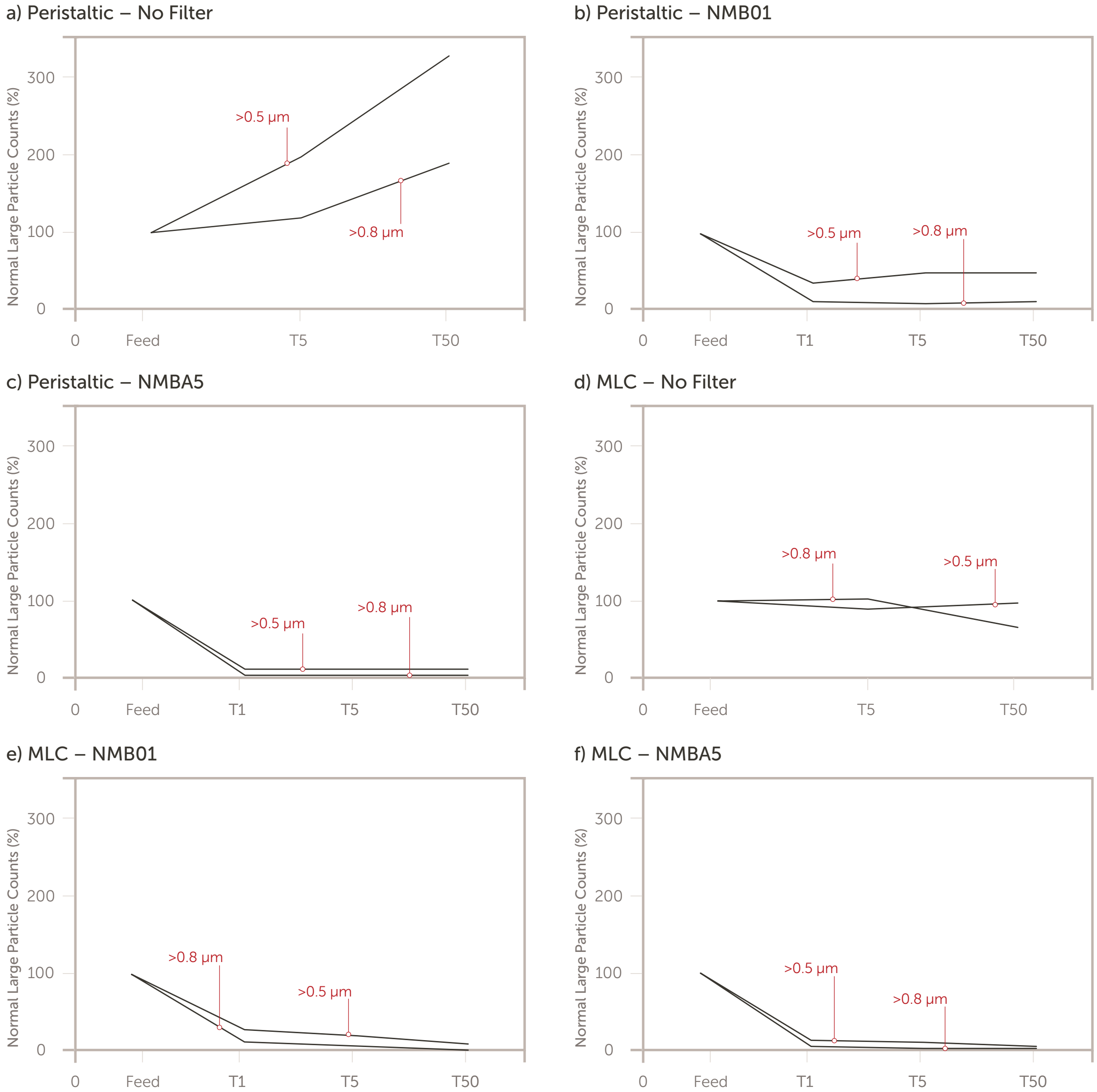


Figure 4. Colloidal silica (1wt%) circulation by peristaltic pump: a) No filter, b) NMB01, c) NMBA5; MLC pump: d) No filter, e) NMB01, f) NMBA5. Particle agglomeration increased with turnovers using peristaltic pump without filters.

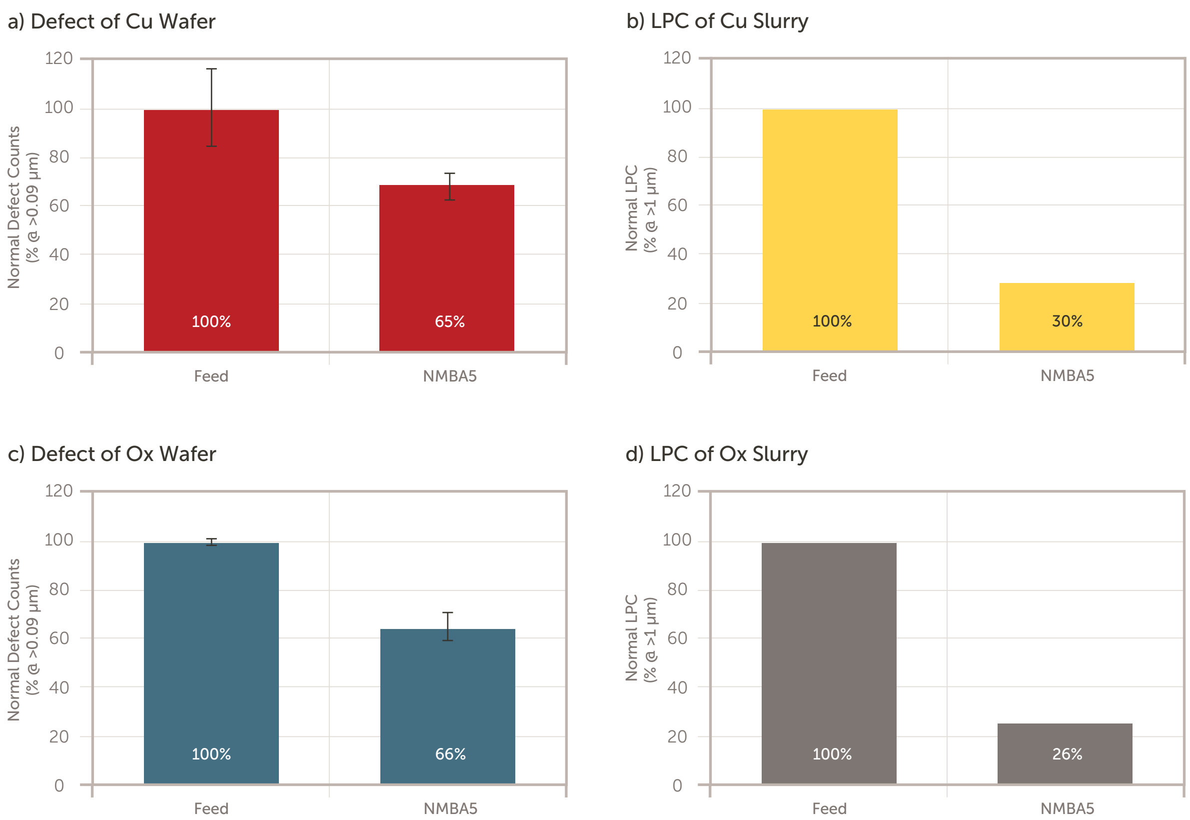


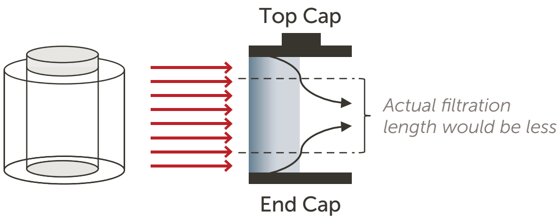
Figure 5. Normalized defect counts on polished wafers and LPC of polishing slurry. a) Cu defect counts and b) LPC of feed and NMBA5 filtered colloidal silica Cu slurry. c) Oxide defect counts and d) LPC of feed and NMBA5 filtered ceria slurry.

OPTIMIZING CMP LIQUID FILTERS: UNDERSTANDING LENGTH AND BOUNDARY EFFECT

This study examines how filter length and structural boundaries affect CMP slurry filtration performance, including retention, pressure drop, and stability. By comparing 1-inch, 5-inch, and 10-inch filters, it offers guidance on selecting optimal filter sizes to balance efficiency, cost, and space for different industrial needs.

Filter length significantly impacts filtration efficiency, pressure drop, and lifespan. Longer filters (e.g., 10-inch) offer greater surface area, improving particle capture and reducing clogging, making them ideal for high-flow applications. Shorter filters are better suited for low-flow setups but require more frequent replacement. Structural boundary effects – such as top and end caps – reduce effective filtration area, especially in shorter filters. As shown in Figure 6, this boundary effect can cause variability in retention performance and must be considered when selecting filters for precision CMP applications.

Both 1-inch and 10-inch filters showed similar retention trends, but longer filters provided greater stability and lower pressure drop, supporting higher flow rates. While short filters can model performance, they are less reliable for long-term or high-demand use. For practical applications, 10-inch filters offer the best efficiency and durability, while 5-inch filters deliver nearly the same stability (only 2% less) with space savings. In contrast, 1-inch filters suit early testing or low-flow scenarios. Overall, 5-inch filters present the most versatile option for CMP operations.



CARTRIDGE LENGTH	OFFICIAL LENGTH	BOUNDARY EFFECT	RATIO
10″	254 mm	5 mm	2%
5″	127 mm	5 mm	4%
1″	25.4 mm	5 mm	20%

Figure 6. Boundary effect and impact ratio.

ADVANCED FILTRATION STRATEGY FOR FINE PARTICLE CONTROL IN CMP PROCESSES

This study investigates the behavior of FPC under high shear conditions and evaluates the performance of Entegris' APR filter technology. Through a series of experiments, the research demonstrates that APR filters effectively remove both FPC and LPC without altering the working particle size distribution, offering a robust solution for improving wafer yield and reliability.

Fine particles (<30 nm) threaten wafer integrity by causing underlayer defects. To assess FPC agglomeration under high shear, colloidal silica slurry underwent 7 days of shear and 2 days of static aging. As shown in Figure 7, FPC counts rose slightly during shear but returned to near-original levels after aging, indicating minimal agglomeration.

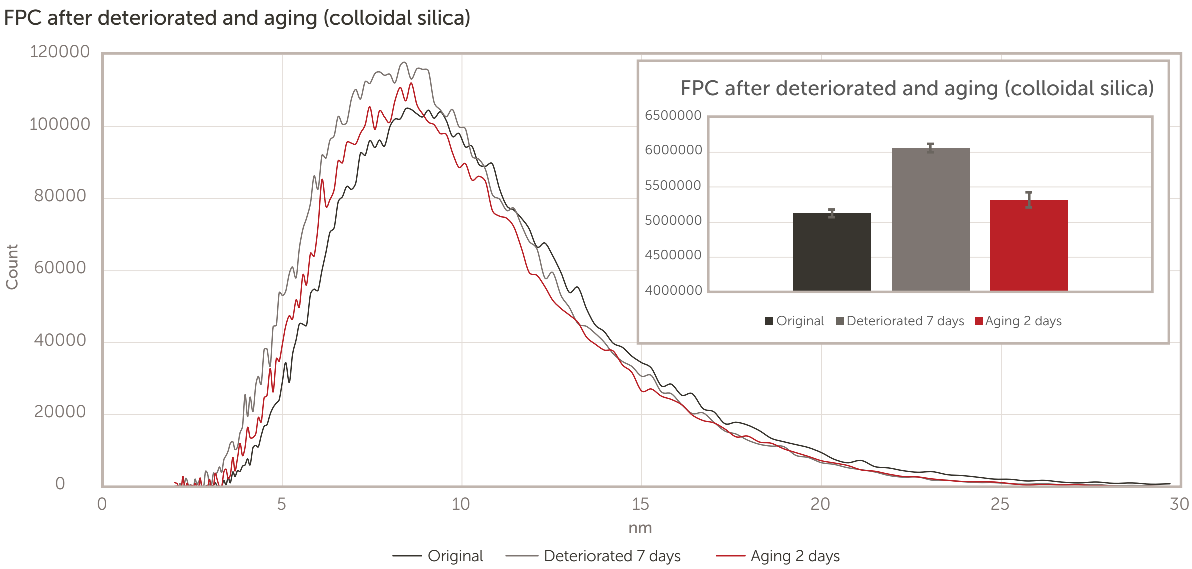


Figure 7. FPC after deteriorated and aging (colloidal silica).

After APR filtration, FPC counts dropped by 45% (2.77E+06 → 1.52E+06) and remained stable post-shear and aging (Figure 8). In contrast, LPC counts fell sharply (93% retention for >0.29 µm) but rebounded under shear to near pre-filtration levels, indicating vulnerability to shear-induced agglomeration (Figure 9). PSD analysis confirmed APR filters maintain slurry integrity, and consistent FPC behavior in aluminum-based slurry validates performance across abrasive types.

Total count: FPC after deteriorated and aging with sample filtered by APR

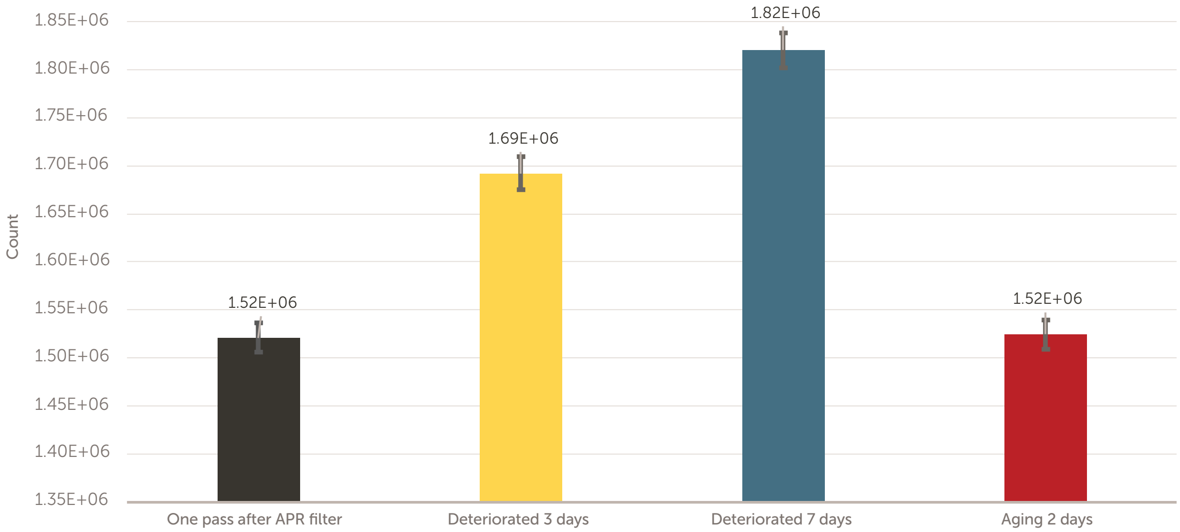


Figure 8. FPC after deteriorated and aging with sample filtered by APR.

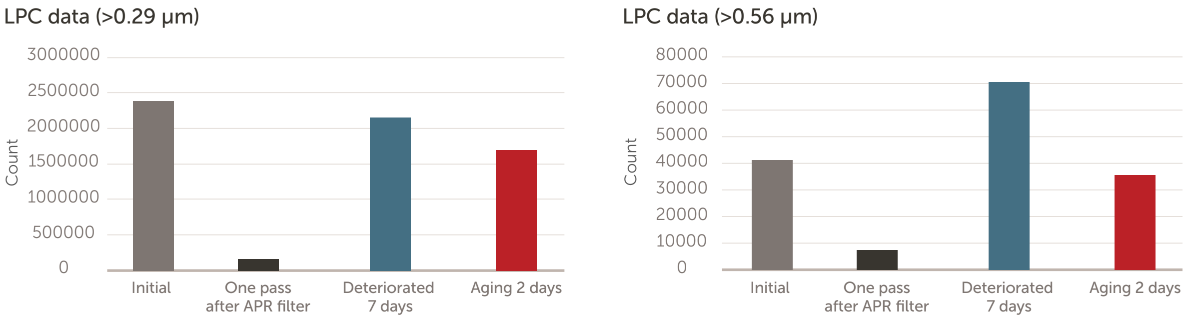


Figure 9. LPC after deteriorated and aged with sample filtered by APR.

CONCLUSION

As CMP processes advance toward finer technology nodes, effective slurry filtration becomes indispensable for defect reduction and yield improvement. This study demonstrates that filtration performance is influenced by multiple factors, including slurry chemistry, flow dynamics, and filter design. Nanofiber filters mitigate shear-induced agglomeration and significantly reduce LPC, while APR filters extend this capability by capturing both LPC and FPC without altering particle size distribution. Filter length optimization further enhances retention stability and operational efficiency, with 5-inch filters offering a practical balance between performance and space constraints. Collectively, these findings provide a comprehensive framework for selecting filtration strategies that ensure process stability, minimize defects, and support the stringent requirements of next-generation semiconductor manufacturing.

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