Effect of Shear Stress and Pump Methods on CMP Slurry

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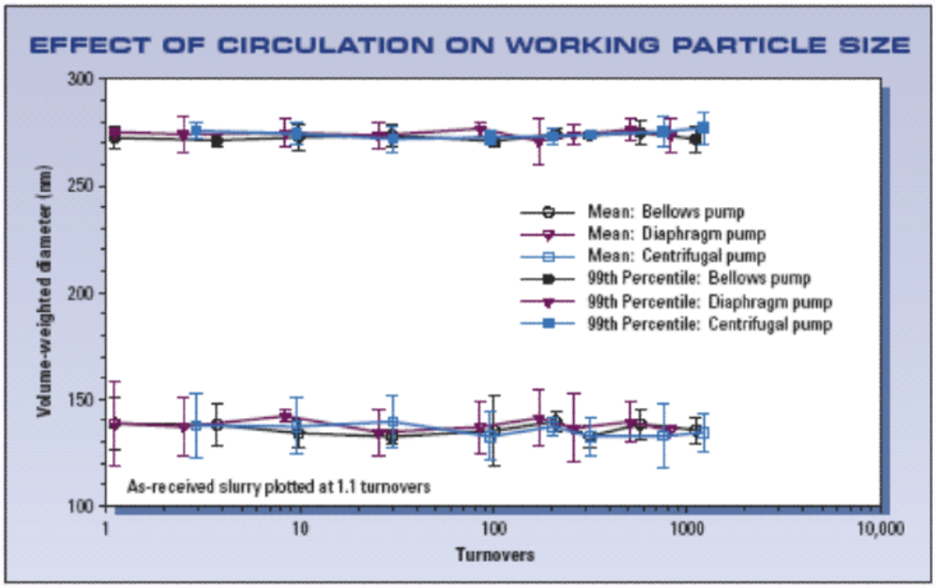


1. The effect of pumps on the slurry working particle size distribution.

Chemical mechanical polishing (CMP) slurries are stabilized suspensions of small particles that are used to planarize wafers. Agglomeration of the particles can occur if the interparticle repulsive forces are overcome. Storage time, environmental conditions, and handling and distribution can reduce the effectiveness of these forces, thereby reducing the stability of the slurry. Shear stresses arising in slurry distribution pumps are claimed to be large enough to overcome the repulsive forces, thereby leading to agglomeration of particles in the suspension.[1] The presence of large particles and agglomerates in CMP slurries has been clearly related to microscratches and other defects on polished wafer surfaces.[2-4] Thus, gentle handling of the slurry in bulk distribution systems is an important factor in maintaining high CMP process yield.

At a Glance

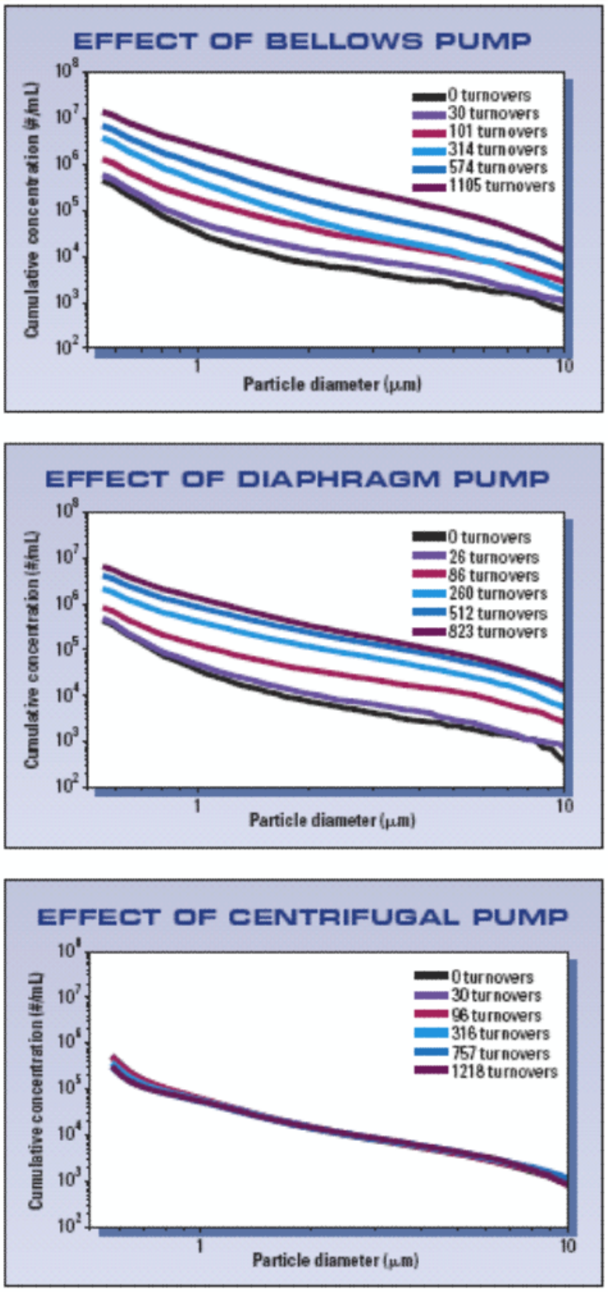
Conventional wisdom suggests that shear stresses generated by centrifugal pumps are too high to allow use of the pumps for delivery of shear-sensitive slurries. This article shows that a shear-optimized centrifugal pump can circulate slurry with minimal damage, compared with traditional slurry delivery methods. Formation of large particles, which can cause wafer defects and limit the life of system filters, was significantly less with a centrifugal pump.

Traditionally, bellows and diaphragm positive displacement pumps and vacuum-pressure systems have been a widely accepted means of bulk slurry delivery. Positive displacement pumps are generally accepted as low-shear devices because of their relatively low speeds of operation, while centrifugal pumps, which typically operate at higher speeds, are usually perceived as high-shear devices. As a result, there exists a preconception in the semiconductor industry that centrifugal pumps are not suitable for delivery of shear-sensitive CMP slurries.

A similar bias was encountered in the medical field regarding the use of centrifugal pumps until about 15 years ago. The general consensus was that, since the natural heart acts like a positive displacement pump, the gentlest type of artificial blood pump would be a positive displacement pump. However, the surprising result of several scientific studies was that exactly the opposite is true.[5-8] Shear-optimized centrifugal pumps were found to cause significantly less hemolysis (destruction of blood cells) than peristaltic pumps. Further research showed that blood damage caused by shear forces is remarkably low as long as the shear level stays below a threshold of ~400 Pa. If this threshold is exceeded, the hemolysis rate increases abruptly.[9] In a shear-optimized centrifugal blood pump the shear level always stays below this hemolysis threshold. In a peristaltic pump, however, the blood in the occlusion area is exposed to forces that massively exceed the critical level and rupture the blood cells.

The same problem occurs in the valves of diaphragm and bellows pumps. Most of the fluid, which is pumped by traditional CMP "dispense engines," is exposed to very low-shear force levels. However, a very small fluid portion, which is trapped in the valves during closure, sees tremendously high pressures of up to 10^6 Pa. In a centrifugal pump, the whole fluid volume is exposed to moderate shear levels of 10^2-10^3 Pa generated by the rotating pump vanes.

Does a similar shear threshold exist for CMP slurries as it does for blood? Can a shear-optimized centrifugal pump actually be gentler to slurry than a positive displacement pump? Although we do not have enough information to address the former question, this study addresses the latter question by comparing the working particle size distributions (PSDs) and large particle tails of a Cabot Semi-Sperse 12 silica slurry circulated by bellows, diaphragm and centrifugal pumps.



2. These charts compare the effects of a bellows pump (top), diaphragm pump (middle) and centrifugal pump (bottom) on the slurry large particle tail.

Experimental methods

A pump-driven system was assembled to circulate Semi-Sperse 12 oxide slurry (Cabot Microelectronics Corp., Aurora, Ill.). A diaphragm, bellows or centrifugal pump could be installed in the system. Pulse dampeners were used downstream of the bellows and diaphragm pumps, per manufacturer recommendation. Each pump was used to circulate 12 L of slurry at a flow rate of 30 ±1 L/min, temperature of 20 ±2°C, and outlet pressure of 30 ±5 psig. A length of PFA tubing was used to reduce the pressure to ambient before returning the slurry to the tank. Steps were taken to avoid entrainment of air into the slurry, and a humidified nitrogen blanket over the tank prevented drying. The slurry was circulated for ~1000 tank turnovers (i.e., 1000 passes through the pump). Slurry used in each test was taken from the same drum. Samples were withdrawn from the tank, diluted, and the PSDs of both the working particles and the large particle tail were measured at various times during each test.

The size of the working particles (particles typically ~0.1 μm in diameter that are performing the planarization) was measured with a NICOMP 380 ZLS submicron particle sizer (Particle Sizing Systems, Santa Barbara, Calif.), which determines particle size by dynamic light scattering. The PSD of the working particles is important because it affects the planarization rate during a wafer-polishing process.

The PSD of the large particle tail was measured with an AccuSizer 780 optical particle counter (Particle Sizing Systems). The large particle tail, considered to be particles ≥0.56 μm in diameter, can cause surface scratches during planarization. Furthermore, an increase in the concentration of large particles may prematurely clog filters, thereby reducing their lifetime and increasing maintenance costs.

Results and discussion

Figure 1 shows the effect of slurry circulation on the PSD of the working particles. Data are shown for both the mean particle diameter (volume weighted) and the 99th percentile particle diameter (i.e., particle size that is greater than the diameter of 99% of all particles). Error bars represent ±3 SDs. Typically, slurry passes through equipment, providing the motive force ~100 times before it is used to polish wafers (i.e., the slurry is "turned over" ~100 times).[10] No significant change in mean particle size or 99th percentile particle diameter was observed with any pump after 1000 turnovers.

Changes in the cumulative concentrations of large particles as a function of particle diameter for each pump type are shown in Figure 2. Each curve represents the PSD after a given number of turnovers. The concentration of large particles (≥0.56 μm) increased significantly within 100 turnovers using either the bellows or diaphragm pumps. After 1000 turnovers, concentrations were 20-70× higher than the initial concentrations (depending on the particle size). Meanwhile, in the centrifugal pump system, large particle concentrations remained relatively unchanged.

The particle concentration increase was observed to be essentially linear with turnovers for both the diaphragm and bellows pumps. These results suggest that these pumps generate a constant number of large particles per pump stroke, ~200,000 and 410,000 particles ≥1.0 μm per pump stroke, respectively. Since the pumps deliver a constant volume per stroke, this is equivalent to a concentration increase of

1340 and 2050 particles/mL $\geq$1.0 µm per pump pass, respectively. Although this appears to be a rather large amount of particle agglomeration, the particle generation is equivalent to only a 3-6% concentration increase per pass through the pump, since the initial particle concentration in the slurry is $\sim$35,000 particles/mL $\geq$1.0 µm.

Summary

The type of pump used to circulate slurry can have a significant effect on concentrations of large particles in the slurry. In a series of tests, centrifugal, bellows and diaphragm pumps were used to circulate Semi-Sperse 12 silica slurry. The size distributions of the working particles did not change significantly after being circulated for 1000 tank turnovers by any of the three pumps. However, the size distributions of the large particle tails showed that use of the bellows or diaphragm pumps caused significant increases in the numbers of large particles. Use of the centrifugal pump caused only a minimal change in the large particle concentrations. Contrary to conventional beliefs, the centrifugal pump appears to cause fewer changes in the slurry PSD. •

References

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