Effect of Shear Stress and the Influence of Different Pump Methods on CMP Slurry

Mark Litchy, CT Associates, Inc.
Reto Schoeb, Levitronix GmbH

At a Glance

Conventional wisdom suggests shear stresses generated by centrifugal pumps are too high to allow use of the pumps for delivery of shear sensitive slurries. This paper shows that a shear-optimized centrifugal pump is capable of circulating slurry with minimal damage compared to 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 compared to other delivery methods.

Introduction

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.

Traditionally, bellows and diaphragm positive displacement pumps and vacuum-pressure systems have been widely accepted means of bulk slurry delivery. Positive displacement pumps are generally accepted as low shear devices due to 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 approximately 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 which 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.

Experimental methods

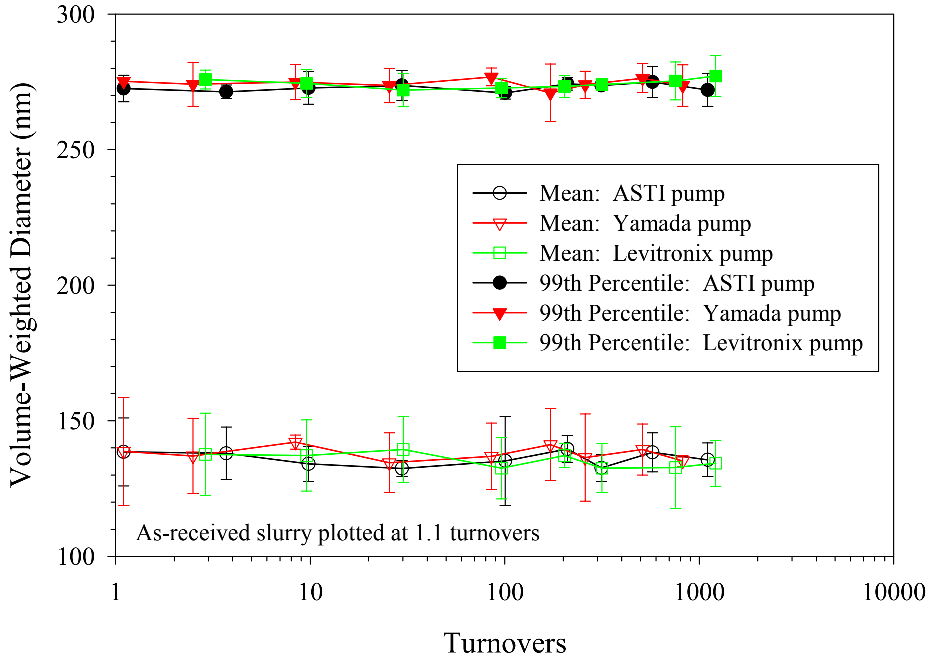
A pump-driven system was assembled to circulate SemiSperse® 12 oxide slurry (Cabot Microelectronics, Corporation, Aurora, IL). A diaphragm, bellows, or centrifugal pump could be installed in the system. Pulse dampeners were used downstream of the bellows and diaphragm pumps, per manufacturer recommendation. Each pump was used to circulate 12 L of slurry at 30 ± 1 Lpm at a temperature of 20 ± 2°C and an 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 approximately 1,000 tank turnovers (i.e. 1,000 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 CA) that 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, Santa Barbara CA). The large particle tail, considered to be particles ≥ 0.5 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

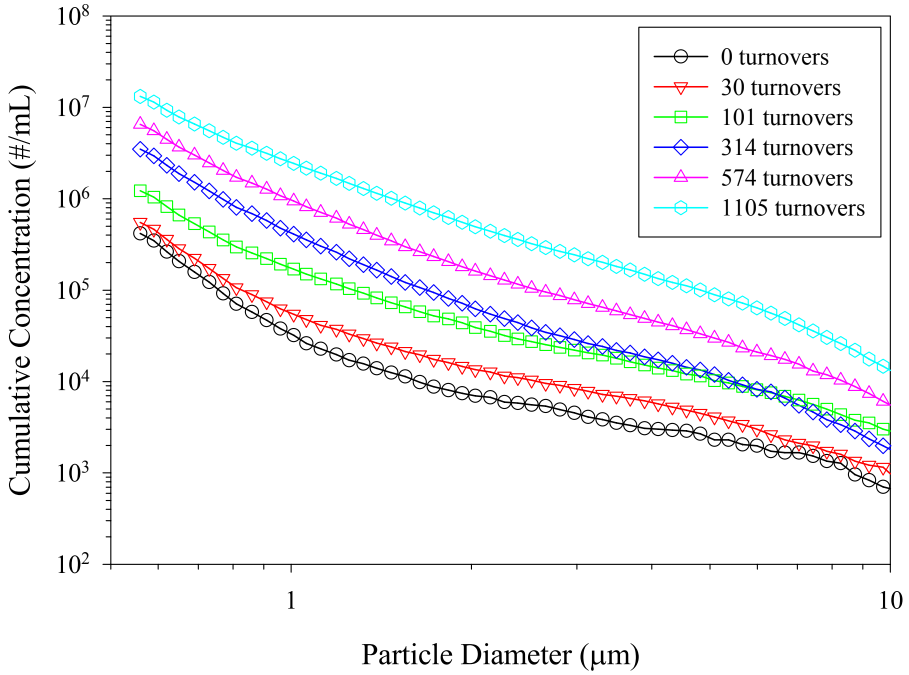
Figure 1 shows the effect of slurry circulation on the PSD of the working particles. Data are shown for both the mean particle diameter (volume weighted) and the 99th percentile particle diameter (i.e. particle size which is greater than the diameter of 99% of all particles). Error bars represent ± 3 standard deviations. Typically, slurry passes through equipment providing the motive force approximately 100 times before it is used to polish wafers, i.e. the slurry is “turned-over” approximately 100 times.[10] No significant change in mean particle size or 99th percentile particle diameter was observed with any pump after the slurry was turned-over 1,000 times.



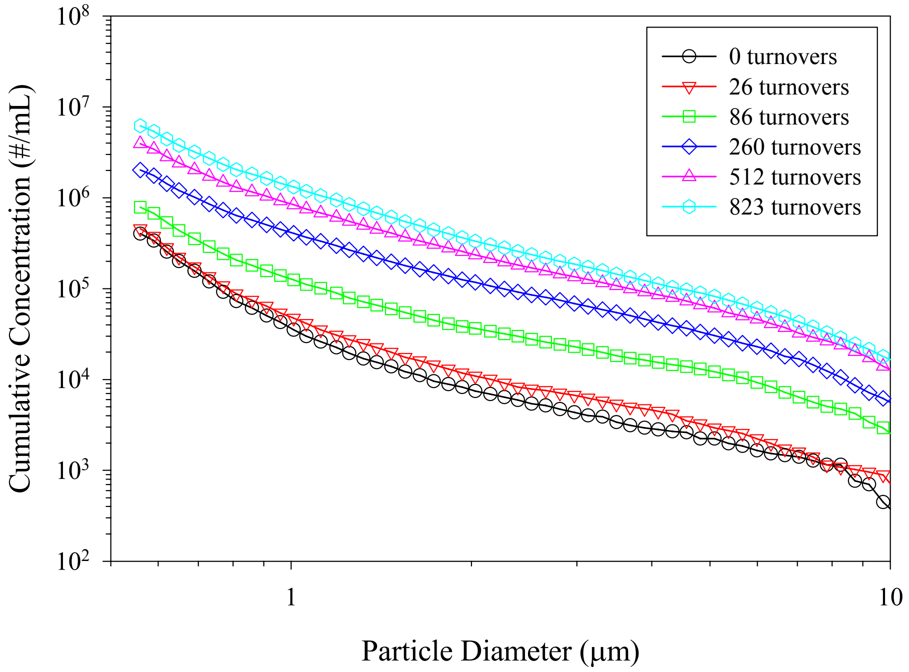
1. Effect of pumps on the working particle size distribution

Figure 2 shows changes in the cumulative concentrations of large particles as a function of particle diameter for each pump type. 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 1,000 turnovers, concentrations increased 20-70 times higher than the initial concentrations (depending on the particle size). Meanwhile in the centrifugal pump system, large particle concentrations remained relatively unchanged.

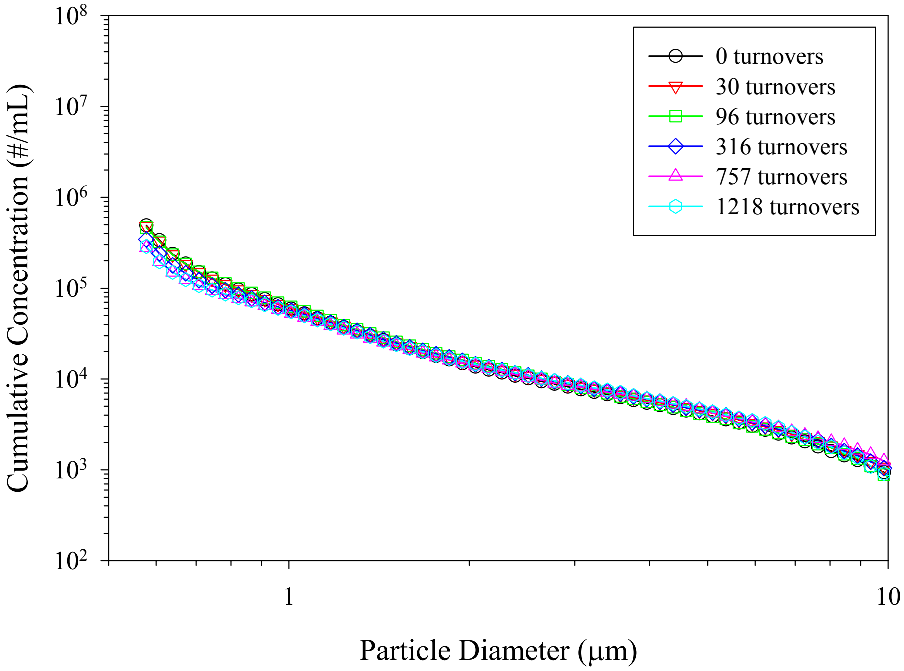
The particle concentration increase was observed to be essentially linear with turnovers for both the diaphragm and bellows pumps. These results suggest that these pumps generate a constant number of large particles per pump stroke, approximately 200,000 and 410,000 particles ≥ 1.0 µm per pump stroke, respectively. Since the pumps deliver a constant volume per stroke, this is equivalent to a concentration increase of about 1,340 and 2,050 per ml ≥ 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 approximately 35,000 particles/mL ≥ 1.0 µm.



2a. Effect of bellows pump on the slurry large particle tail



2b. Effect of diaphragm pump on the slurry large particle tail



2c. Effect of centrifugal pump on the slurry large particle tail

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, or 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 1,000 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 than either the bellows or diaphragm pump tested, and thus may be an appropriate choice for use in slurry delivery systems.

References

[1] J. Bare, B. Johl, T. Lemke, "Comparison of Vacuum-Pressure vs. Pump Dispense Engines for CMP Slurry Distribution," *Semiconductor International*, January 1999.

[2] G. Vasilopoulos, et al, "STI CMP Defect Reduction with Slurry Filtration," *VLSI Multilevel Interconnect Conference (VMIC)*, June 2000.

[3] T. Nishiguchi, "CMP Consumable Technologies in PERL Hitachi," *ERC Retreat & IAB Meeting*, 2001.

[4] K. Nicholes et al, "Analysis of wafer defects caused by large particles in CMP slurry using light scattering and SEM measurement techniques," *2003 Proceedings of the Eighth International Chemical-Mechanical Planarization for*

ULSI Multilevel Interconnection Conference (CMP-MIC), Marina Del Ray, CA, February 2003.

[5] T. Oku, H. Harasaki, W. Smith, Y. Nose, “Hemolysis. A comparative study of four nonpulsatile pumps,” *ASAIO Trans*, July-Sept. 1988.

[6] O. Moen et al, “Roller and centrifugal pumps compared in vitro with regard to haemolysis, granulocyte and complement activation,” *Perfusion*, March 1994.

[7] T. Nishinaka, H. Nishida, M. Endo, H. Koyanagi, “Less platelet damage in the curved vane centrifugal pump: a comparison study with the roller pump open heart surgery,” *Artificial Organs*, Vol. 18, Issue 9, Sept. 1994.

[8] I.S. Morgan, M. Codispoti, K. Sanger, PS. Mankad, “Superiority of centrifugal pump over roller pump in paediatric cardiac surgery,” *European Journal of Cardiothoracic Surgery*, May 1998.

[9] R. Paul et al, “Shear stress related blood damage in laminar couette flow,” *Artificial Organs*, Vol. 27, Issue 6, June 2003.

[10] Personnel communication with J. Kvalheim, BOC Edwards Chemical Management Division, Chanhassen, MN, March 2003.