Effect of a Maglev Centrifugal Pump on Slurry Health and Defect Rates

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1. INTRODUCTION

CMP slurry characteristics (slurry health) may change significantly due to improper handling techniques and protocols. Extensive slurry recirculation or improper distribution hardware may lead to slurry agglomeration or large particle formation that may result in increased wafer defects. There have been many studies related to CMP slurry characterization to quantify the effects of extensive handling on slurry metrology parameters and colloidal stability, but only a few studies have focused on the effects of various distribution methods such as different pump and vacuum-pressure dispense technologies.[1-7]

Silica based CMP slurries are colloidal suspensions of small particles that are stabilized by repellent electrostatic forces. Agglomeration of the particles can occur if external forces applied to the suspended particles are strong enough to overcome these opposite electrostatic forces. Once the particles are close enough, the attractive van der Waals forces become stronger than the repellent electrostatic forces and the particles can stick together.[8] Shear stresses arising in slurry distribution pumps are claimed to be large enough to overcome the inter-particle opposite forces, thereby leading to agglomeration of particles in the suspension.[9] The presence of large particles and agglomerates in CMP slurries has been clearly related to micro-scratches and other defects on polished wafer surfaces.[10-12] Thus, gentle handling of the slurry in bulk distribution systems is an important factor in maintaining a high CMP process yield.

Conventional wisdom suggests shear stresses generated by centrifugal pumps are too high to allow the use of these pumps for delivery of shear sensitive slurries. Our research shows, however, that a shear-optimized, magnetically levitated (maglev) centrifugal pump is capable of circulating slurry with less damage compared to various pump slurry delivery methods. The moderate shear level to which the slurry is exposed in maglev pumps seems to actually have a beneficial effect on the slurry by breaking apart loose agglomerates.

2. PRIOR INVESTIGATIONS OF SLURRY DELIVERY PUMPS

In earlier studies, the influence of pumps on fumed silica slurry was investigated.[9,13,14] In one of these studies, three different pumps: a bellows pump, a diaphragm pump and a maglev centrifugal pump were tested in the same slurry circulation system. During the test, slurry samples were periodically withdrawn from the tank and analyzed for changes in the Particle Size Distributions (PSD). The ratios of the cumulative particle concentrations relative to the initial particle concentrations for particles ≥ 0.56 μm as a function of turnovers for each pump type are shown in **Figure 1**. The concentration of large particles (≥ 0.56 µm) increased 2.3 –2.9 times within 100 turnovers using either the bellows or diaphragm pumps. After 1,000 turnovers, concentrations increased 18-28 times. Meanwhile in the centrifugal pump system, large particle concentrations remained virtually unchanged after 100 turnovers and actually decreased by about 40% after 1000 turnovers.

The decrease in large particle concentrations after pumping the fumed silica slurry with the Levitronix pump was actually a beneficial effect. Independent tests by other groups using the same type of slurry actually confirmed these results.[14] It seems that the moderate shear levels to which the slurry is exposed in a maglev centrifugal pump might even help to break up loose agglomerations. The question remained, whether this effect was just a peculiarity when pumping fumed silica slurry or whether the same effect could be reproduced with other types of slurries.

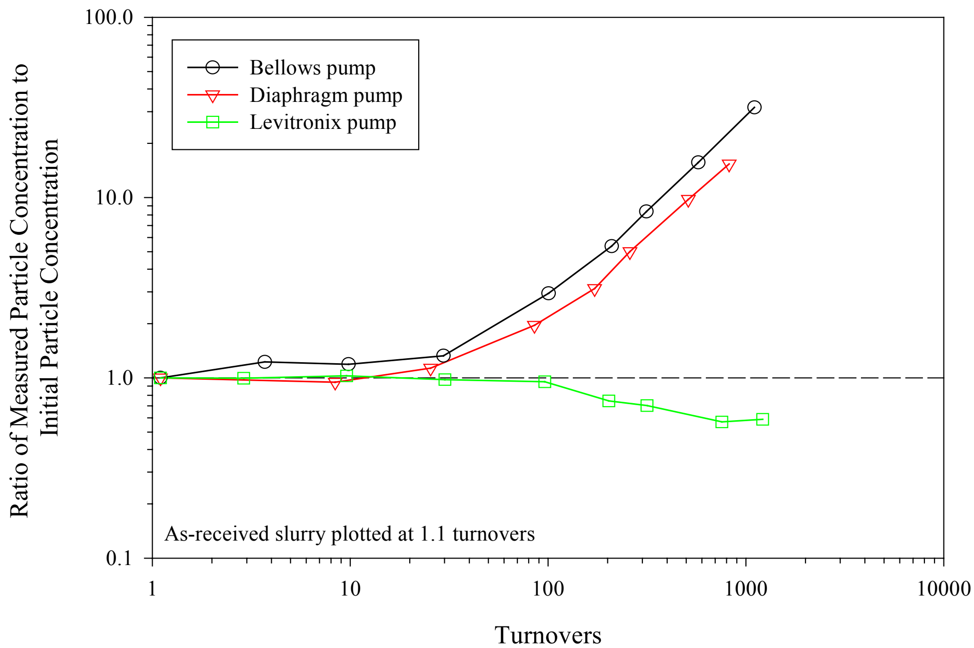

Figure 1: Effects of different pumps on fumed silica slurry in a test-loop on the concentration of particles larger than 0.56 µm.

3. MAGLEV PUMP TEST WITH KLEBOSOL® 1501-50

In order to answer this question, the Levitronix pump was also tested with a different silica slurry: Klebosol® 1501-50. This KOH based slurry consists of essentially spherical liquid grown silica particles. The different manufacturing process allows tighter control of the actual particle size, which on average is 50 nm (**Figure 2**).

3.1. Slurry Health Test Setup

The Levitronix pump was used to continuously circulate 130-L of Klebosol® 1501-50 slurry at a flow rate of 11-Lpm and an outlet pressure of 2.2 psig. The slurry was recirculated approximately 5 times per hour and about 1700 times over the course of 14 days. Samples were taken after every 24 hours (122 turnovers) and analyzed for viscosity, density, solids concentration, zeta potential, mean PSD and large PSD.[15]

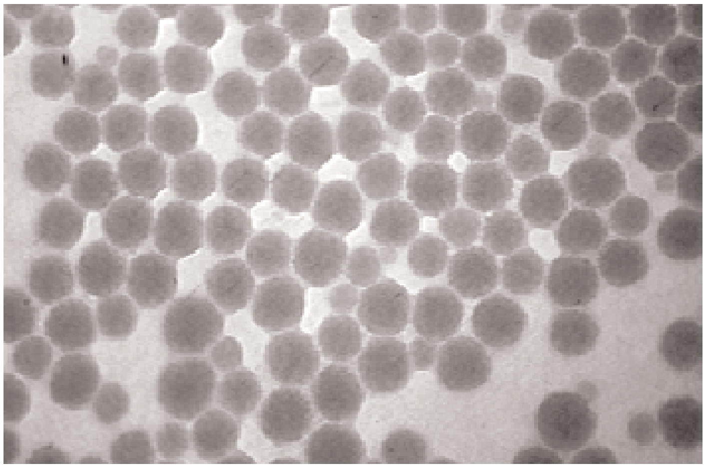

Figure 2: Precisely Controlled Klebosol® Silica Particles

3.2. Slurry Health Test Results

No change in viscosity, density, or solids concentration could be found during the course of the 14 day test (**Figure 3**). The zeta potential (**Figure4**), which was measured with a Matec ESA 9800, and the mean PSD (**Figure 5**), measured with a Nicomp® 380, also remained unaffected. The PSD of the large particle tail clearly decreased over time (**Figure 6**). Compared to fresh slurry, the concentration of large particles ≥ 0.59 µm was ~10% lower after 1700 turnovers.

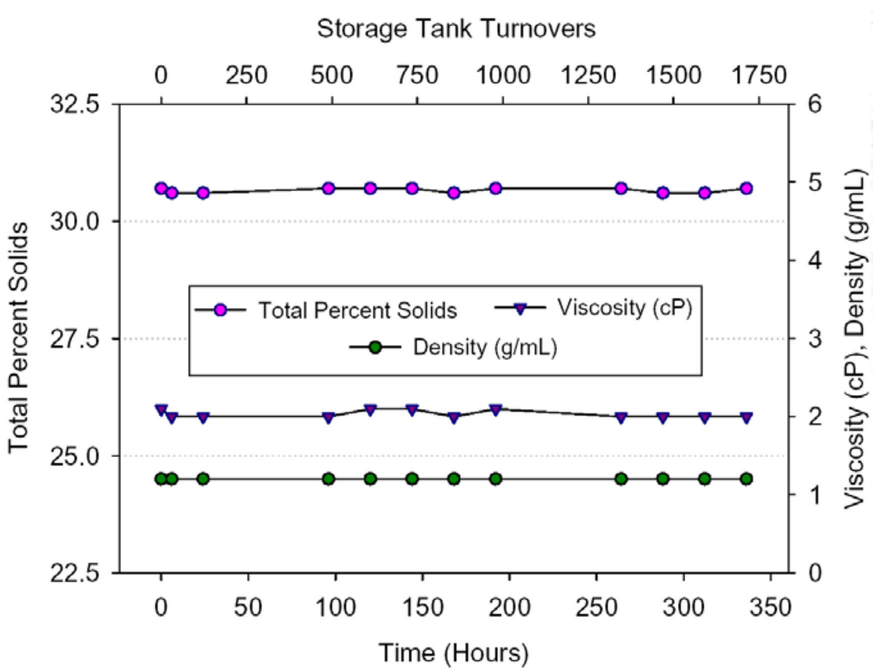

Figure 3: Viscosity, density, and solids concentration of Klebosol® 1501-50 slurry recirculated with a Levitronix pump.

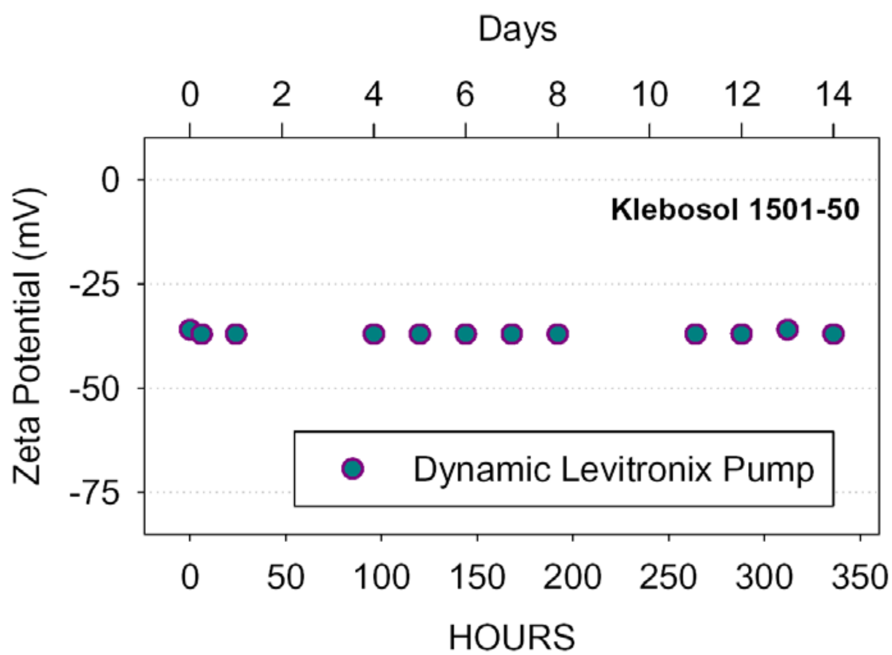

Figure 4: Zeta Potential of Klebosol® 1501-50 slurry recirculated with a Levitronix pump.

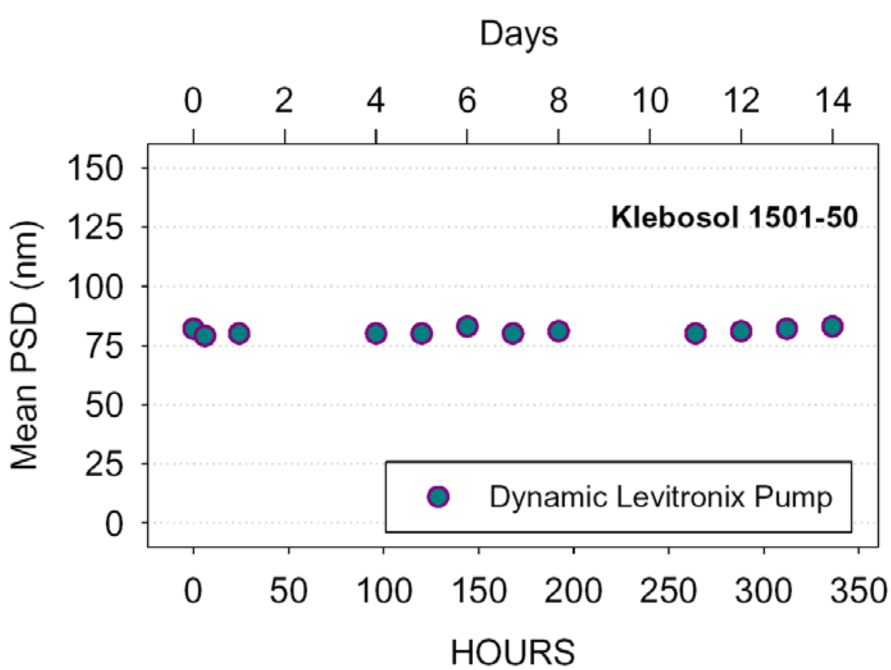

Figure 5: Mean PSD of Klebosol® 1501-50 slurry recirculated with a Levitronix pump

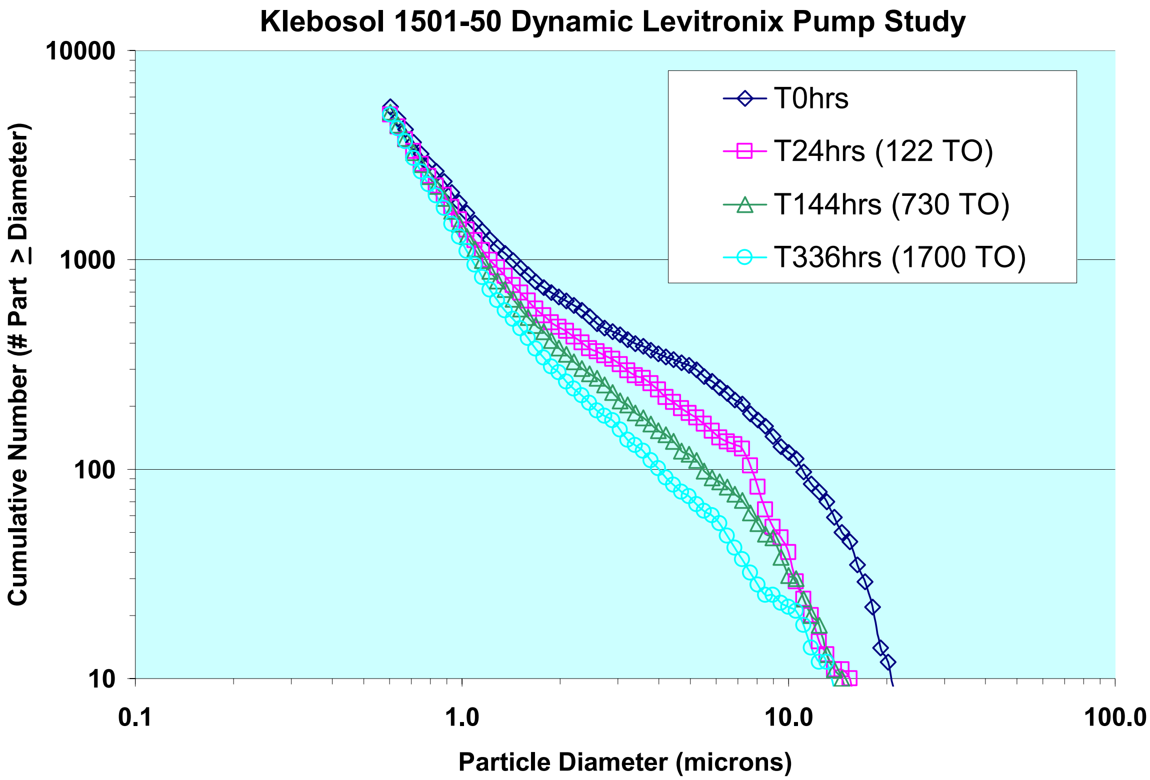

Figure 6: PSD of the large particle tail for Klebosol® 1501-50 slurry recirculated with a Levitronix pump

3.3. Polishing Test Setup

The PSD data of the slurry recirculation test with Klebosol® 1501-50 implied that treatment with a Maglev centrifugal pump might even be beneficial for the slurry. In order to test this hypothesis, a total of 18 test-wafers were polished with an Applied Materials Mirra® tool. **Figure 8** shows the normalized defect rate of the wafers, which were polished with fresh slurry (blue) as well as with slurry, which was circulated 1700 times with the Maglev centrifugal pump (red). In order to eliminate the influence of the polisher head, test wafers were run with all 3 heads.

3.4. Polishing Test Results

Comparison of the removal rates between Wafers polished with fresh Klebosol® 1501-50 slurry (blue bars) and Wafers polished with Klebosol® 1501-50 slurry, which had been circulated 1700 times (maroon bars) is represented by **Figure 7**. The measurements show no significant difference between the Wafers polished with fresh slurry and Wafers polished with circulated slurry. The result is consistent with the unaffected mean particle concentration.

As shown in **Figure 8**, the normalized defect rate of wafers polished with fresh Klebosol® 1501-50 slurry (blue bars) and with slurry, which was circulated 1700 times with a Levitronix pump (maroon bars). The defect data from all three polisher heads shows a slightly lower defect rate when the slurry was first circulated with the Levitronix pump. The reduction in defect rate is consistent with the reduced large particle concentration of the Klebosol® 1501-50 slurry which was circulated 1700 times with the Levitronix pump.

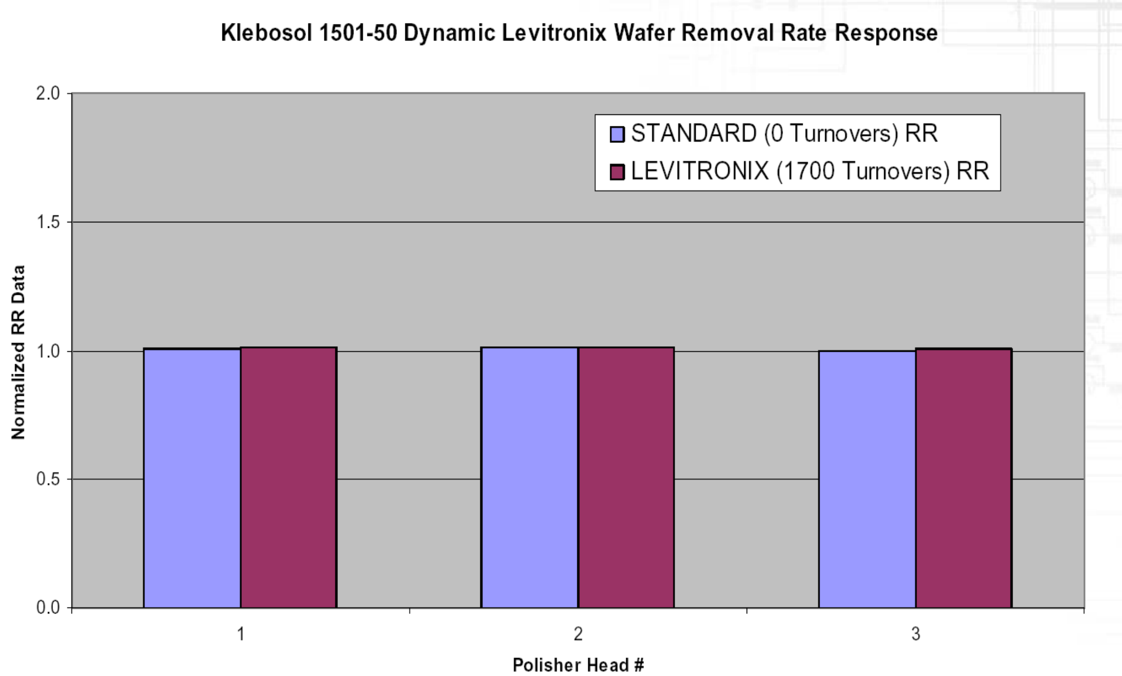

Figure 7: Normalized removal rate with fresh slurry (blue) and with slurry, which was circulated 1700 times with a Levitronix pump (maroon)

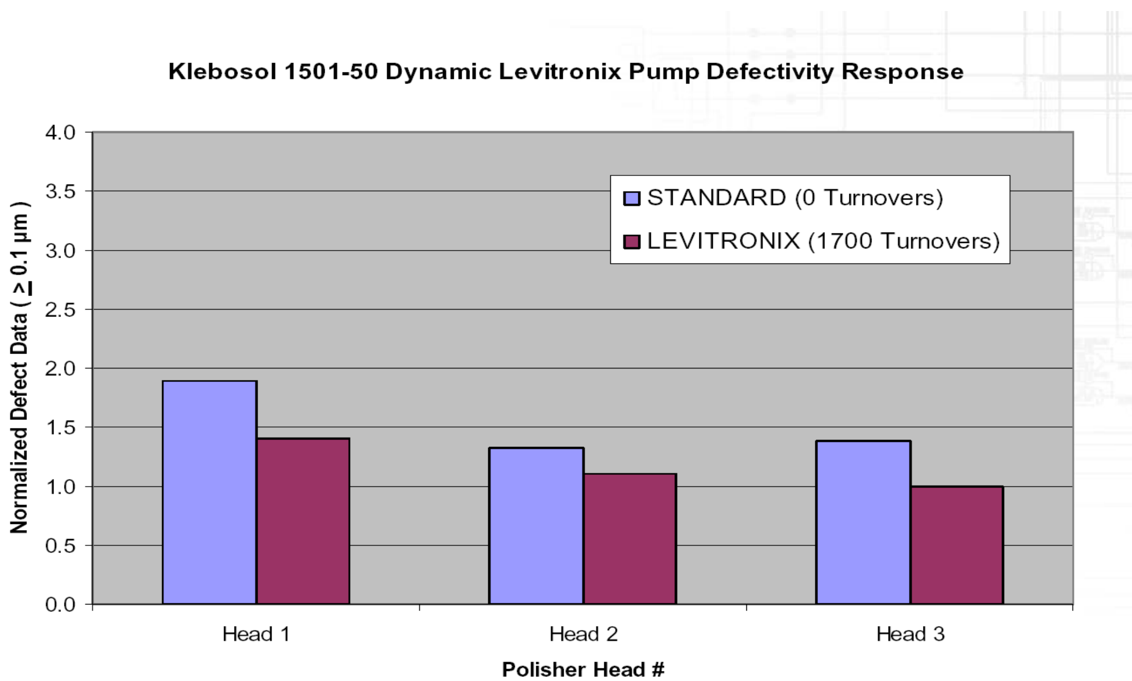

Figure 8: Normalized defect rate of wafers polished with fresh slurry (blue) and with slurry, which was circulated 1700 times with a Levitronix pump (maroon)

CONCLUSIONS

In a highly accelerated aging test, Klebosol® 1501-50 was subjected to 1,700 storage tank turnovers during a 14-day test period in a magnetically levitated centrifugal Levitronix pump. This is 1,400 – 1600 more turnovers than a slurry endures in typical fab usage.

- No significant changes in normal slurry health were observed after being subjected to 1,700 storage tank turnovers.
- No settling or thickening of the slurry was observed at any point in the loop and also verified by viscosity measurements.
- There was no increase in large particle size distribution, indicating no increase in particle agglomeration. Actually a slight decrease was observed overall.
- Defect levels showed slightly less defects overall on all three polishing heads even after being subjected to a high number of turnovers. Additionally, no difference in wafer RR was observed.
- Levitronix Maglev pump is compatible with Klebosol 1501-50 slurry as shown by the results of this study.

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