Next Generation Composite, Rigid Filter for Chemical Mechanical Planarization

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Abstract- Chemical Mechanical Planarization (CMP) slurries are formulated to provide a narrow particle size distribution, within a chemically active carrier, for chemical and mechanical material removal during the construction of integrated circuits. The role of CMP filtration is to reduce the Large Particle Counts (LPC) without affecting the particle size distribution, solids content, or the chemistry of the slurry.

Two different filter structures were compared in this study. One consisted of Melt Blown Fibers (MBF). The other consisted of a Composite, Rigid Filter (CRF) matrix. LPC reduction can be achieved at significantly high flow rates and low pressure drop with CRF. These improvements were attributed to physical properties of the materials of construction used in the CRF. Specifically, there is a distinct advantage in surface energy and rigidity. This was not the case with MBF. The elevated pressure drop experienced across the MBF filter may lead to slurry property changes, including shear stress and agglomeration.

I. INTRODUCTION

Polyolefin filters produced using MBF with a gradient pore structure are commonly used in the industry to filter LPC from CMP slurry. MBF filters have demonstrated to be more compressible as compared to filters manufactured with non-compressible, rigid depth structure characteristics. The new generation CMP filter (CRF) aims to improve upon LPC reduction at expanded process capabilities.

Traditional MBF filters consist of wrapped webs or direct blown fiber on a core. These structures increase in fiber density from filter upstream to downstream. LPC are reduced when the CMP solution is processed through these filters as shown in Fig. 1.

The new generation CMP filter is a composite, rigid structure. It consists of a thermally bonded polyolefin bi-component coarse fiber matrix and microfiber-glass web inserts that are the primary clarification and classification zones, as shown in Fig 2.

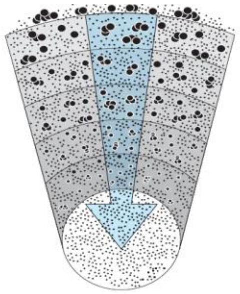

Fig. 1 MBF Structure

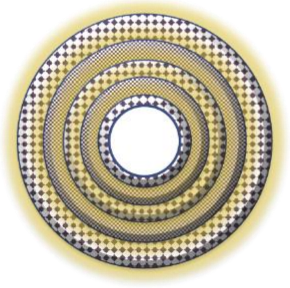

Fig. 2 CRF Structure

II. EXPERIMENTAL PROCEDURES

In order to study the flow versus pressure drop characteristics of both filters, silica based CMP slurries with mean particle sizes of 80 and 130 nm were used. Data was compared based on the same flux. The solid loading varied from 5% to 20 wt.%. The 80 and 130 nm slurries had a pH of 10.4 and 10.8, respectively. The CRF filters were rated at 70 nm [1]. The MBF filters were rated at 100 nm. One gallon of well distributed slurry was processed through each filter in a re-circulating loop via a diaphragm pump. The output of the pump was calibrated by adjusting its RPM while measuring the volume of CMP slurry with a graduated cylinder and a stop watch. The slurry was processed at moderate and high flux rates. Two instruments were used for analyzing particle size and distribution of the slurries: the FX-Nano sensor in a 780 AD system from Particle Sizing Systems, and the Mastersizer 2000™ G/S particle sizer from Malvern Instruments.

III. RESULTS AND DISCUSSION

A. Flow Rate and Pressure Drop Performance

Manufacturers and end users of CMP slurry seek to process as quickly as possible to maximize productivity. However, high pressure drop and shear is often an offshoot of elevated flow rates. The effect of high pressure drop and resulting shear on LPC increase has been studied [2]. It is important to reduce all actions or design features that promote LPC increase.

Flow rate test results utilizing 130 nm slurry at 5%, 10% and 20 wt.% solids is shown in Fig. 3. The MBF filter exhibited an immediate increase in differential pressure while yielding low flow rate. Conversely, CRF demonstrated significantly higher flow rate at considerably lower differential pressure in every instance.

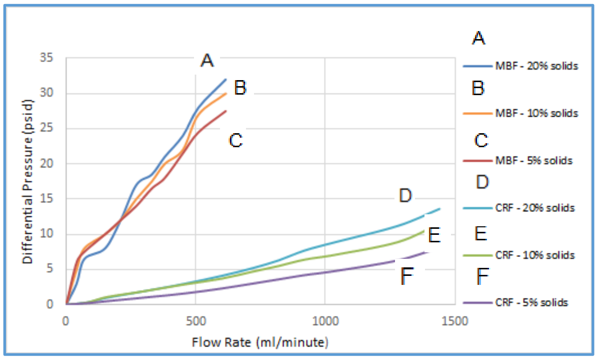

Fig. 3. Differential Pressure vs Flow Rate for 130 nm Silica Slurry with Various Percent Solids

Fig. 4 depicts flow rate performance at various solids content at 10 psid. CRF offers approximately seven times greater flow rate as compared to the MBF filter at 20% solids and it continues to improve as the percent solids is lowered.

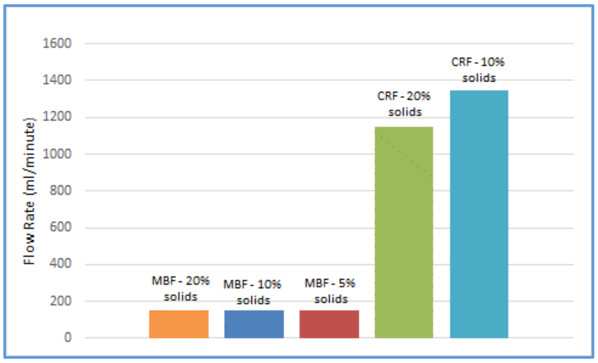

Fig. 4. Flow Rate at 10 psid for 130 nm Silica Slurry at Various Percent Solids

Flow rate test results, utilizing the 80 nm slurry at 3.5%, 7% and 14 wt.% solids, yielded comparable results to what was observed with the 130 nm slurry, and is shown in Fig. 5

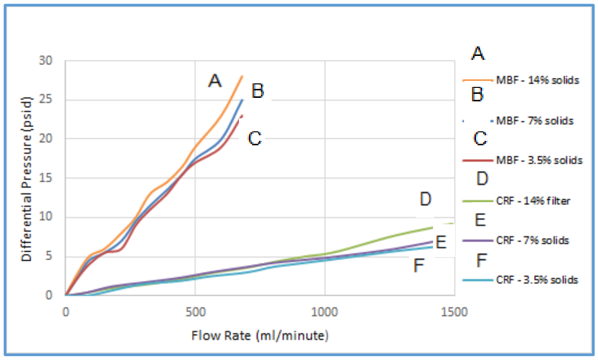

Fig. 5. Differential Pressure vs Flow Rate for 80 nm Silica Slurry with Various Percent Solids

The clarifying layer in the MBF filter is comprised of polypropylene fibers. The classifying/clarifying layers in the CRF is made of micro-glass fibers. The high flow rate/low pressure drop of the CRF can be attributed to the significant difference in surface tension between the polypropylene (30.01 mN/m) and the glass (500 mN/m) [3].

The polyolefin fiber matrix in the CRF yields low pressure drop for the micro-glass polishing layers. Thus, they do not contribute significantly to flow restriction or pressure drop increase. Conversely, the MBF structure utilizes wrapped layers of hydrophobic polypropylene to form a mechanical sieve. Naturally, this will result in flow restriction and pressure drop increase.

Unlike polypropylene, glass is hydrophilic and can be readily wet by CMP slurries, which are aqueous solutions. The wettability difference between polypropylene and glass is shown in Fig. 6, which depicts slurry on each filter media. The CMP slurry forms a droplet with a wetting angle of 115° on the MBF (Fig. 6A). The CMP slurry penetrates completely into the glass fiber media, forming a zero wetting angle (Fig. 6B).

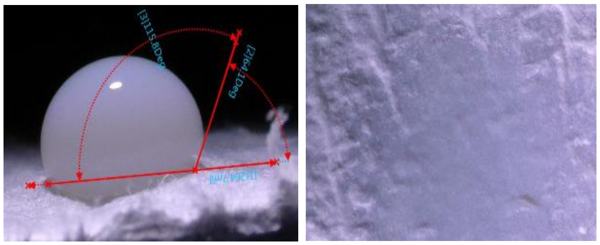

Fig.6.(A) side view of CMP drop on MBF, Fig. 6 (B) top view of CMP on glass media

For the MBF design, the surface energy associated with polypropylene requires considerable force to mechanically transfer slurry through the media. In order to achieve submicron rating specifications for an advanced CMP slurry formulation, a filter with finer fibers that are positioned closer together is needed. As a result, the fiber spacing that the CMP slurry has to pass through is drastically reduced, resulting in higher fiber surface area. This condition requires more energy for the CMP slurry to overcome in order to flow through. Hence, high pressure drop and inability to operate at elevated flow rates are an expected consequence of this design.

Conversely, at a comparable micron rating, the CRF design offers a significantly lower pressure drop at the same flow rate. This is due to the hydrophilic nature of the glass. Specifically, the high surface energy associated with the glass fiber (500 mN/m) enables it to be readily wetted by the CMP slurry (70 mN/m). The driving force for system energy reduction directly translates to lower pressure drop, higher throughput and lower shear stress on the slurry.

B. LPC Reduction Performance

The particle size and distribution for the as-received 130 nm silica slurry is shown in Fig. 7. The reduction of the peaks at 1 µm and larger is the main objective of LPC reduction.

Reduction of 0.3-5 µm particles from the 130 nm slurry with 20 wt.% solids, processed at a flux rate of 75 ml/minute, is shown in Fig 8. The data was generated after 4 and 8 tank turns for each filter.

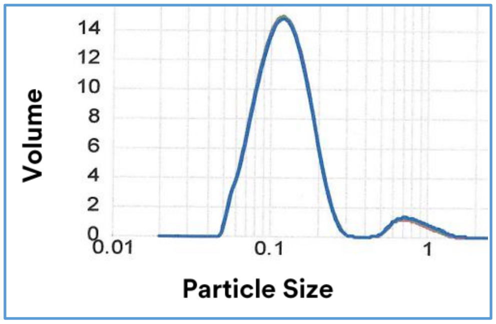

Fig. 7. Particle size and distribution of the 130 nm silica slurry

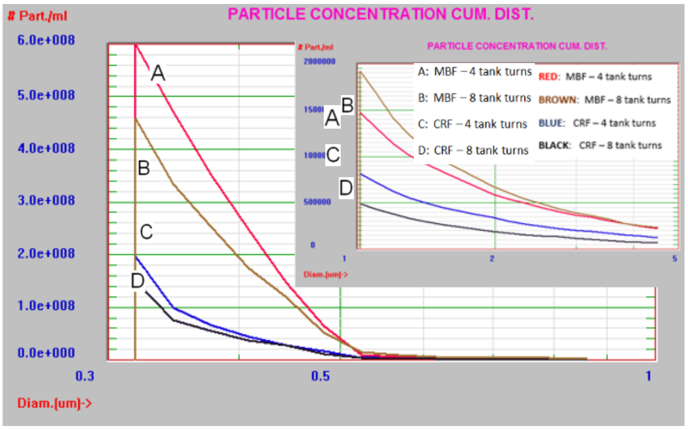

Fig. 8. Post-Filtration particle count of 130 nm 20% Solids Silica Slurry at ml/minute for 0.3-1 and 1-5 µm range.

Note that at both tank turns the CRF yielded performance that exceeded that of the MBF. This is true at both the smaller (0.3-1 µm) and larger (1-5 µm) particle size ranges. Also evident, as the number of tank turns increases, more particles are filtered out by the CRF. It is interesting to note that at the 1-5 µm particle size range, the MBF filters less particles at a greater number of tank turns. This is indicative of a structural shortcoming of MBF to be addressed later.

Reduction of 0.3-5 µm particles from the 130 nm slurry with 20 wt.% solids, processed at a flux rate of 250 ml/minute, is shown in Fig 9. The data shown represents the average of five separate analyses conducted between 15-20 tank turns. More particles are filtered out as compared to testing of the same filter at the lower flux rate shown in Fig. 9. However, it is important to recognize that the data shown at the 250 ml/minute flux rate represents particle counts after 15-20 tank turns. Evaluating particle reduction performance of MBF at this flux rate was not practical due to its elevated starting differential pressure of 15 psid.

The 130 nm slurry at 5 wt.% solids was tested to represent the processing conditions of CMP end users. Reduction of 0.3-5 µm particles from the 130 nm slurry with 5% solids, processed at a flux rate of 250 ml/minute, is shown in Fig. 10.

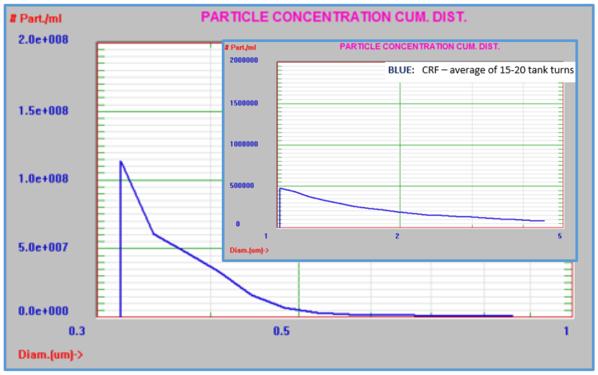

Fig. 9. Post-Filtration Particle Content of 130 nm 20% Solids Silica Slurry @ 250 ml/minute for 0.3-1 & 1-5 µm range.

The data represents the average of five separate analyses conducted between 10-15 tank turns. Again, performance of the CRF is superior to that of MBF at both micron size ranges.

The trends exhibited at both the moderate and high flux rate with high and low percent solids held true with the 80 nm slurry as well.

The structure of the CRF does not change as differential pressure rises during filtration. Conversely, the MBF structure compresses during filtration. This compression inevitably leads to pore structure alteration and potential subsequent release of trapped particulate into the effluent stream. This is likely the phenomenon that occurred when more tank turns resulted in an increase in particle counts as shown in Fig 8. This behavior limits the use of the MBF filters to pressure drops of 10 psid or lower. In addition, since differential pressure doesn't rise as particulate is trapped in the filter matrix, it is challenging to know when the filter life is exhausted.

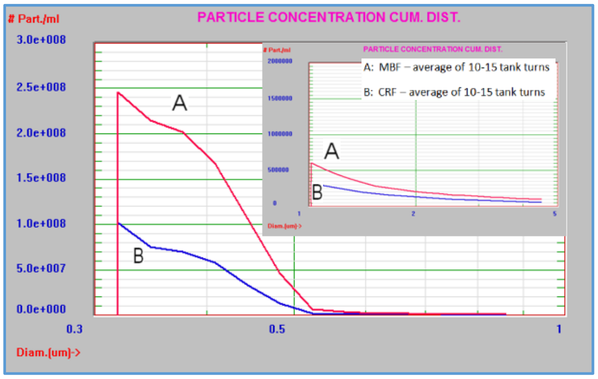

Fig. 10. Post-Filtration particle count of 130 nm 5% Solids Silica Slurry @ 250 ml/minute for 0.3-1 & 1-5 µm range

The differential pressure rise between the CRF and MBF filters are shown in Fig. 11 for the 130 nm slurry with 20 wt.% solids. The pressure drop increase with the CRF is gradual, representing a pore plugging mode. In contrast, the pressure drop increase with the MBF filter is steadily decreasing. The pressure drop decrease is likely explained by offloading of LPC or continued wetting of the MBF over time.

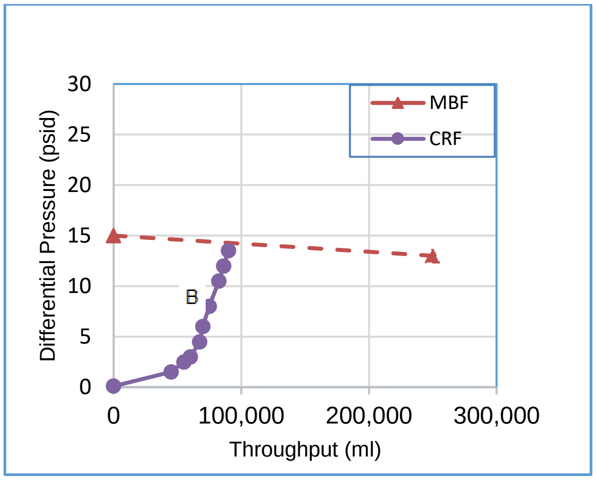

Fig.11. Differential Pressure vs Throughput for 130 nm Silica Slurry with 20 wt.% Solids at 250 ml/min

IV. CONCLUSION

The new generation, composite, rigid filter provides high flow rate with extremely low pressure drop and notable improvement in reduction of LPC when compared with hydrophobic MBF filters. Its scope of relevance includes CMP slurry of various mean particle size and percent solids.

REFERENCES

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[2] Feng-Chi Chang, z Siddharth Tanawade, and Rajiv K. Singh, "Effects of Stress-Induced Particle Agglomeration on Defectivity during CMP of Low-*k* Dielectrics", *Journal of The Electrochemical Society,* **156** (1) H39-H42 (2009)

[3] Wu. S. "Polymer Interface and Adhesion" (1982), MARCEL DEKKERR, Inc. New York.