Application Note #1018

Benchtop Mechanical Testing Improves CMP Quality Control and Process Optimization

Chemical mechanical polishing (CMP) is a global planarization process that takes advantage of the synergetic effect of mechanical abrasion and chemical reactions in polishing wafers. It has become a critical technique in modern IC manufacturing processes, from patterning steps and position lithography to topography control and ensuring proper wafer surface characteristics. These applications have increased in both number and importance as continual demand for shrinking device sizes and increased performance have driven ever more stringent semiconductor manufacturing requirements. For this reason, it is important that new CMP technologies meet these requirements and be able to adapt to new demands as they arise. This application note discusses how Bruker's TriboLab CMP addresses these challenges through CMP quality control and CMP optimization and allows for the optimized evaluation of new CMP technologies by end users and suppliers (in series and in parallel).

CMP Quality Control

Many of the components involved in CMP equipment ownership lead to a high cost of maintenance. To put this into perspective the CMP market exceeded 2.5 billion dollars in 2013, and the consumables market exceeded that of the systems market. This high cost of ownership can be attributed to inefficiencies, such as excess downforce (Fz) and polish rate drift. Bruker's TriboLab CMP offers a way to combat these issues with easy-to-use evaluation routines, which include monitoring and quality control recipes, as well as robust capabilities for custom test creation.

CMP is used in conjunction with accurate and precise metrology measurements to control the quality and consistency of components required for the CMP processes. Any variability in the chemicals or the process conditions can map directly to process variation and polish metrics, such as selectivity, defects, corrosion, and polish rate. These problems can be addressed with the use of the TriboLab CMP, on a much smaller scale before they have larger detrimental effects with full-scale CMP usage.

One great advantage of the TriboLab CMP is the small footprint. The benchtop, compact CMP system is designed to perform mechanical testing and characterization by replicating full-scale polishing process conditions as well as replicating consumables wear. It has pressurizing mechanisms on the wafer carrier, which also provides the rotational motion. The integrated sensors measure and monitor the vertical force (Fz) as well as coefficient of friction (COF) and acoustic emission during the experiments. This can be utilized for end-point detection, enabling the system to perform a range of specific test conditions. To perform polishing experiments on the TriboLab CMP, round or square coupons can be cut from full-size wafers to fit inside the benchtop wafer holders. The largest advantage being a substantial reduction in costs and wastage, making R&D costs and efforts much more manageable.

Pad conditioning strongly affects pad-wafer interactions and thus impacts the reproducibility of the removal rate. Removal rate drift and "glazed" pads are serious problems when it comes to this. Therefore, it is critical to condition the surface of the pad either in-situ (during polishing) or ex-situ (in between polishing runs) to regenerate the pad surface, produce new pad asperities and remove the glazed areas. Pad conditioners are designed and tailored for each situation to maintain consistent and desired roughness and porosity throughout a pad's lifetime. As a result, slurry transport and distribution will be consistently maintained on the pad, and polishing quality, removal rate, and planarity will all be consistent, controlled, and maintained throughout a pad's lifetime. This will, in turn, lower the cost of CMP equipment ownership. The TriboLab CMP accommodates the same pad conditions used on full-size models, enabling users to easily monitor these issues. It can be used to condition the pads both in-situ and ex-situ, while monitoring and measuring changes in height, COF, normal load, and temperature over time. The general idea is that the faster the COF stabilizes during conditioning, the more effective the conditioner is, and therefore the lifetime of a pad is extended.

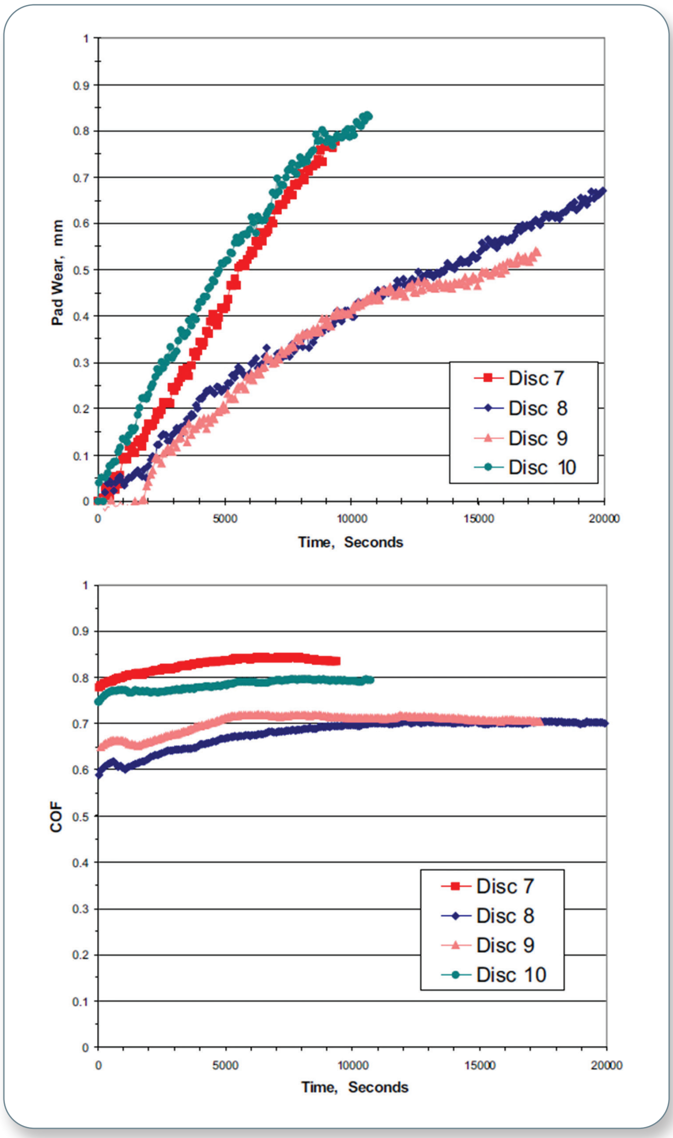


Figure 1. The top graph shows pad wear rate in millimeters. Conditioning discs 8 and 9 show lower wear. The bottom graph shows friction variation with time, and conditioning discs 8 and 9 also showed longer stabilization time (in terms of COF).

An example of CMP experiments performed using a TriboLab CMP is provided in Figure 2 (from Yan Pan et. al. 2010 J. Electrochem. Soc. 157 H1082), focusing on the effect of slurry on copper polishing. These tests were done specifically to understand and develop a physical model for the effect of sodium dodecyl sulfate (SDS) on polishing. For context, SDS surfactants were added with different concentrations to the slurry, and the slurry also contained glycine, hydrogen peroxide, and silica particles. For copper CMP, the slurry should meet two requirements, first any mechanically abraded copper oxide particles should dissolve in the slurry and get removed from the polishing interface. Second, the oxidation and polishing rate of the surface that encounters the pad must be higher than the removal rate of underlying copper. The graph below demonstrates that without surfactant the material removal rate was high, but there were many scratches and pits on the polished surfaces. This corresponds to the highest COF, possibly due to mechanical abrasion. Increasing surfactant concentration resulted in a series of behaviors, including a reduction of removal rate, followed by a small rise in removal rate. The COF, however, continued to decrease as more SDS was added. This correlated with changes in the chemical properties of the surface, leading to surface variation and affecting zeta potential, wettability, and ionic strength of the surface. It was found that increasing the SDS concentration to 0.75 mM/l resulted in reduced amount of scratches and corrosion during polishing and a more effective CMP process. This characterization test, and others like it, are necessary for cost minimization.

CMP Process Optimization

Due to the high cost of ownership that comes with CMP systems it is important that the product is functioning at its finest. The TriboLab CMP can aid CMP process optimization through easy-to-use testing programing and monitoring both in-situ and ex-situ.

First, writing recipes has been made easy with the software available. Each recipe can consist of one or several sequences and each sequence can consist of one or several steps. The sequences can run individually or subsequently. All the data channels such as normal force, frictional force (both on the polishing head and conditioning discs), acoustic emission signals, temperature of the pad, and height are saved into data files.

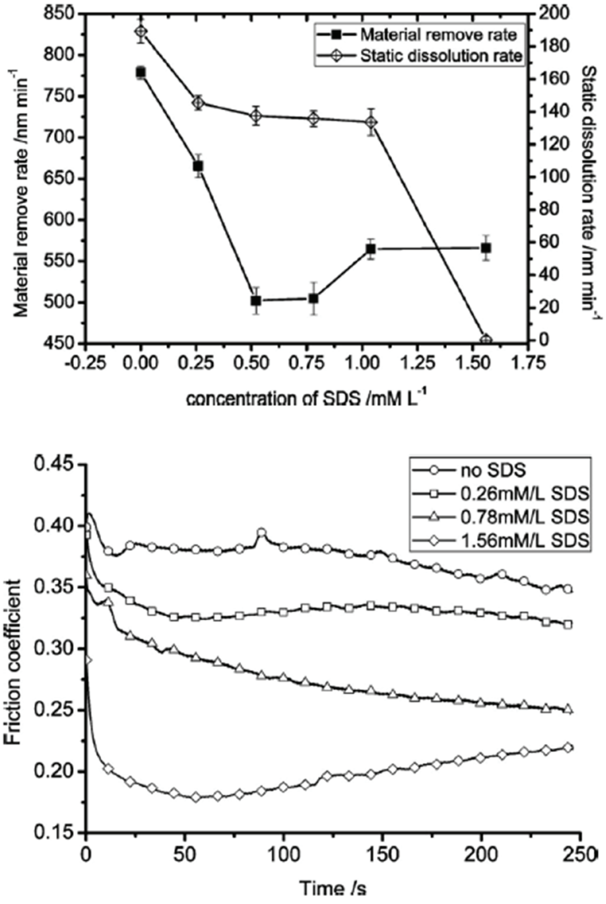
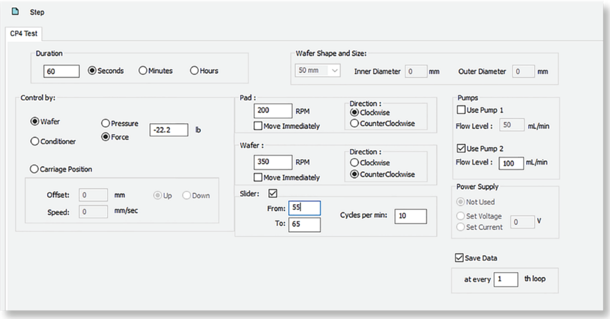


Figure 2. The effect of sodium dodecyl sulfate (SDS) concentration on static dissolution rate and removal rate; polishing copper (top). COF variation with time for different SDS concentrations; polishing copper (bottom).

Inside of each step, as shown in the screenshot in Figure 3, all parameters can be independently altered. This includes load control on the wafer, or the conditioner. The carriage position control is also available. The velocity, direction of motion, as well as the lateral cycles can be changed. Lastly, the water and slurry feeds are also programmable and can be automated; the pumps can be turned on or off, or given a specific flow rate. Monitoring the CMP progress in Bruker's TriboLab CMP involves both in-situ monitoring and end point detection.

A variety of end point detection approaches are currently in use in the industry today. These include acoustical and vibrational methods, electrical methods, thermal methods, and frictional and optical methods. Bruker's TriboLab CMP was also designed with this in mind and a variety of endpoint detections are available to evaluate endpoint in the polishing processes. Acoustic Emission (AE) is integrated in the wafer chuck. This will detect a spectrum COF frequencies generated during polishing. AE can be used to detect micro scratches, contamination of layers, elastic plastic deformation of sublayers, and so on.



Duration: 60 ● Seconds ○ Minutes ○ Hours

Wafer Shape and Size: 50 mm Inner Diameter 0 mm Outer Diameter 0 mm

Control by: ● Wafer ○ Conditioner ○ Pressure ● Force -22.2 lb

○ Carriage Position

Offset: 0 mm ● Up ○ Down

Speed: 0 mm/sec

Pad: 200 RPM ☐ Move Immediately

Direction: ● Clockwise ○ CounterClockwise

Wafer: 350 RPM ☐ Move Immediately

Direction: ○ Clockwise ● CounterClockwise

Slider: ☑ From: 55 To: 65 Cycles per min: 10

Pumps

☐ Use Pump 1 Flow Level: 50 mL/min

☑ Use Pump 2 Flow Level: 100 mL/min

Power Supply

● Not Used

○ Set Voltage 0 V

○ Set Current

☑ Save Data

at every 1 th loop

Figure 3. Demonstration of TriboLab CMP Software.

The temperature of the pad is also measured during endpoint detection testing. Changes in the COF over time can further be used for endpoint detection with the TriboLab CMP, as can monitoring pad wear (through the monitoring of height). Data from a demonstration of benchtop CMP is given in Figure 4, showing how parallel AE and COF measurements complement each other in detecting endpoints of polishing.

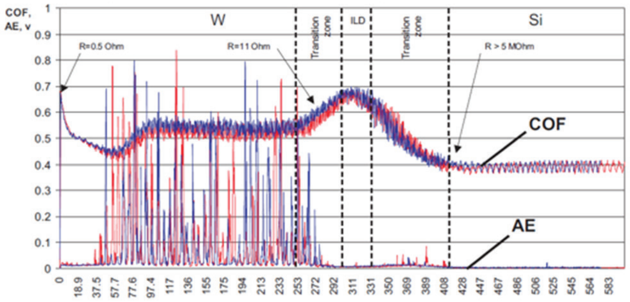


Figure 4. This graph demonstrates both the COF and AE as a product of time spent polishing.

Conclusion

The TriboLab CMP addresses a wide range of recurring and new challenges for CMP use situations. The central problem that is addressed with Bruker's TriboLab CMP is the large amount of resources that are wasted using inefficient CMP development processes. The TriboLab CMP allows for efficient and cost-effective testing of CMP systems for quality control and optimization of CMP processes, large-scale equipment, and consumables. This is accomplished through a range of tribological measurements, easy-to-use software, and a small footprint. As the trends of shrinking device size scales and increasing performance requirements continues, it will become even more critical that CMP is working efficiently and effectively. Bruker's TriboLab CMP accomplishes this in a single benchtop tool designed for both end users and suppliers, in series and in parallel.

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