Mean Residence Time Analysis of CMP Processes

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A newly developed Residence Time Distribution (RTD) technique based on COF is used for real-time fluid dynamics analysis of the pad-slurry-wafer region. Analysis of mean residence time, MRT (i.e. the average time fresh slurry spends underneath the wafer) is used to determine the time constants associated with purging water and slurry from underneath the pad. Knowledge about MRT and the extend of mixing (i.e. dispersion) between entering fluid and leaving fluid is critical for designing CMP processes which reduce the amount of slurry waste.
The study explores a wide range of process and consumables parameters such as relative wafer-pad velocity, wafer pressure, slurry flow rate, abrasive content in the slurry and the pad groove pattern. The ultimate aim of this study is to use fluid dynamics arguments to develop environmentally benign processes and equipment to reduce the amount of water and slurry used during CMP. The study also aims to determine whether any correlation exists between MRT ILD removal rate.

Our research team has developed a new non-optical technique to measure mean residence time (MRT) of slurry in the wafer-pad region as a function of platen speed, pressure and abrasive concentration of the entering and exit slurries. The measurement method takes advantage of the effect of abrasive concentration on COF to construct the C-Curve from which all other fluid dynamics data are derived. The method first allows the system to reach steady state (in terms of COF) using a 25% solids content slurry (viscosity ~ 6 cP). The system then instantaneously switches to a 2.5% slurry (viscosity ~ 2 cP) which is used to 'push out' the 25% slurry allowing the system to reach a new steady state. Finally, the system instantaneously switches back to the 25% solids slurry to check for any potential hysteresis in COF when the 2.5 % solids slurry is being pushed out. Figure 1 (Top) represents this process graphically. The transients in COF during the rise and fall segments of the graph are then used to extract the mean residence times associated with the process. Preliminary results are shown in Figure 2 and 3 (Center & Bottom). Flow rate and MRT are 'nearly' inversely proportional to one another (consistent with basic chemical reactor engineering principals). The slight departure from ideality is due to the fact that in any CMP process, a certain amount of slurry gets wasted by falling off the pad without having a chance to enter the wafer-pad region. In our case, depending on the polishing parameters, the wasted slurry ranges from 5-50 percent. This presents a great opportunity for designing optimum injector positions to reduce slurry wastage.

Increasing pressure increases MRT by causing the wafer to be further pressed against the conforming pad thus making the interface between the wafer and the pad more resistive to flow. The relative change in MRT as a function of applied load can shed further light on the extent of pad compression & the extent of fluid film thickness reduction in a qualitative manner.

Significant hysterisis is present as a result of the solid concentration of the entering and leaving fluids. Generally speaking, less concentrated fluids (having a lower viscosity) are more effective in displacing more viscous media. This process is analogous to using water or steam to displace and recover pockets of viscous underground crude oil. Understanding the effect of fluid viscosity (as dictated by the abrasive content or other additives) is critical for understanding the time constants associated with slurry fluid dynamics and its effects on lubrication.