Task ID: 425.020

<u>**Task Title:</u>** An Integrated, Multi-Scale Framework for Designing Environmentally-Benign Copper, Tantalum and Ruthenium Planarization Processes <u>**Deliverable:**</u> Report on study of pad-wafer and pad-diamond surface interactions</u>

Abstract:

There are two approaches that are most commonly used to describe particle adhesion to surfaces, a thermodynamic approach and a force-based approach. The force approach is most appropriate for the CMP systems considered here. Figure 1 is a schematic showing an asymmetric particle adhering in the vicinity of a rough substrate. The interactions of interest in this case include van der Waals (vdW) and electrostatic (ES) interactions. Chemical bonds are important in many systems, but are not encountered in these proposed studies. Hydrophobic interactions may also be important in aqueous systems, but they are not significant for particles at CMP conditions compared to the other forces. vdW forces are present in all systems, and in the absence of chemical bonding, these forces are the most significant component of the adhesive force when a particle is in contact with or within up to 15 nm of a surface. While ES forces are often described in terms of electrostatic double layers, there are many CMP-relevant cases of particle adhesion where fully-formed double layers do not exist. For this reason, full ES forces, and not simply ES double layer forces, must be considered to describe particlewafer interaction during CMP. Beaudoin and his students have developed a method for measuring and modeling particle-substrate interactions that is partially illustrated in Fig. 1. With this approach, particles of interest are mounted on the tip of atomic force microscope cantilevers and their adhesion forces against substrates of interest are measured directly, in liquids of interest. Following the force measurements, a second AFM cantilever is used to measure the roughness of the particle and substrate, after which a combined FIB/SEM apparatus is used to prepare cross-sections of the particle. The cross-sections, combined with the roughness data, are used to prepare a 3-D model of the particle. The measured substrate roughness is used to develop a 3-D model of the polished surface. Both surfaces are discretized into nanoscale elements, and the vdW and ES forces between the two surfaces are calculated as a function of particle-substrate separation distance. Figure 2 shows a comparison between predicted and measured adhesion forces for a micron-scale silica particle adhering with a TEOS-sourced oxide surface in DI water.



Figure 1. Schematic of existing computation of vdW and ES forces.



Figure 2. Measured (300 measurements) and modeled (1000 predictions) adhesion between Si_3N_4 cantilever with 40 nm radius of curvature (ROC) on tip and chrome (with surface oxide) substrate in DI water.

Technical Results:

There are a number of accomplishments to report. The most exciting are real-time analyses of Cu electrochemistry which may allow a window into the interfacial processes occurring during polishing. Figure 3 shows a home-made guillotine electrode apparatus designed and fabricated in our lab. With this apparatus we can track the electrochemical processes occurring on Cu surfaces in real time, in direct simulation of the electrochemistry that occurs on a Cu wafer after a slurry particle abrades the surface.



Figure 3. Home-made guillotine electrode for real-time observation of Cu electrochemistry at CMP-relevant conditions.



Figure 4. Electrochemical reactions on Cu surface within guillotine electrode (commercial Cu slurry with 5 wt% H_2O_2)

In Fig. 4, a Cu wire (with no Teflon coating) was immersed in commercial Cu slurry containing 5% H_2O_2 in the guillotine electrode and the current (electrochemical reaction rate) was monitored. Figure 4 shows that initially, Cu dissolves, but after about 50 seconds, passivation of the Cu becomes dominant. However, when the wire is cut there is an instantaneous spike in the current due to dissolution, and then an instantaneous return to the passivation driven system. In planned work, the sides of the Cu wire will be Teflon-coated, such that the only electrochemistry being monitored is at the wire tip. This will dramatically enhance the resolution of the studies of Cu behavior during CMP.



Figure 5. Potential oscillations on Cu surface resulting from mass transfer and surface reaction effects in aqueous 2.25 M HCl and 0.43 M H₂O₂.

A balance of mass transfer and surface reaction effects will dictate the surface reactions occurring during CMP. We have studied this phenomenon in detail in a model system, with a goal of developing a modeling framework that can describe these effects. In Fig. 5, the potential oscillations occurring during the dissolution/passivation of Cu in a solution of 2.25 M HCl and 0.43 M H_2O_2 are shown. These were obtained using a Cu disk in a rotating disk apparatus. As the rotational speed of the disk increases, the rate of mass transfer of reactants/products to and from the disk surface increases. As shown in Fig. 5, the frequency and amplitude of the oscillations increase with increasing mass transfer rates, and that they occur more quickly. A preliminary model has been developed in our lab that describes these mass transport and reaction phenomena.