THE RELATIVE FRICTION FORCE CONTRIBUTIONS OF POLISHING PADS AND SLURRIES DURING CHEMICAL MECHANICAL POLISHING

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ABSTRACT
Next generation integrated circuits (IC’s) will require the use of porous dielectric materials with shear strengths much lower than the currently used dense silicon dioxide. The high friction of CMP (chemical mechanical polishing) may damage these porous dielectric materials. This research is being performed to define the nanoscale source of this poorly understood CMP friction to enable development of less damaging CMP processes. It is proposed that the nanoscale friction on the IC from CMP is a variable combination of two-body pad nanoasperity to IC contact and three-body nanocontact of the slurry particle between the pad nanoasperity and the IC surface. This research uses a combination of individual nanoscale friction measurements for CMP of SiO₂, an analytical model to sum these effects, and bench scale CMP experiments to guide the research and validate the model.

INTRODUCTION
In CMP of SiO₂, a workpiece, SiO₂ coated silicon wafer IC substrate, is held in position with a normal load against a closed cell foam, polyurethane polishing (PU) pad (e.g. Rodel IC1000) which is bonded to a rotating turntable. The turntable provides the mechanical input while the chemically-active (KOH dispersed), abrasive, ~100 nm diameter colloidal SiO₂, containing slurry floods the pad and provides the chemical activity for CMP. A very fine material removal is accomplished at the nanoscale level as consequence of the combined mechanical and chemical activity.

UNDERSTANDING CMP FRICTION
Past research indicates friction is predominately a function of the molecular adhesion of two contacting bodies at the nanoscale. Zhou’s [1] work suggested that the material removal during CMP may be a function of nanoscale three body contact where the slurry particle contacts both the counterface (e.g. SiO₂ coated wafer) as well as the pad asperity.

The authors propose that the total CMP friction is the sum of the friction of individual three body contacts of SiO₂ slurry particles trapped between PU pad asperities and the SiO₂ counterpart and individual two body contacts of PU pad asperities and the SiO₂ counterpart. This is shown in Figure 1. Experimental nanoindenter adhesion measurements of SiO₂ particles to both SiO₂ and PU asperities, and PU asperities to SiO₂ set the foundation for this understanding. Each particle and/or asperity contact will generate a friction force corresponding to the nanoscale adhesion measurements. An analytical model will determine the total friction as the product of these individual contact friction forces and the total number of contacts. Bench scale CMP tests will be done to guide the research and to validate the model.

EXPERIMENTAL AND PROCEDURES
Nanoscale friction forces will be measured using nanoindentation and nanoscratch tests. The indenter is equipped with a friction force sensor to measure lateral forces. The test provides results of the interfacial friction of the PU pad and the SiO₂ slurry particle, and the SiO₂ slurry particle and the SiO₂...
Figure 1. Nanoscale roughness between the SiO\textsubscript{2} counterface (above) and PU pad, SiO\textsubscript{2} and slurry particle, and slurry particle and PU pad. Slurry particle ~100-150nm in diameter.

substrate (either dry or soaked in KOH and water solutions). Friction between a small section of pad material and the SiO\textsubscript{2} substrate is also measured. Lastly, a section of pad material with impregnated slurry particles is translated over the substrate creating a more complex testing scenario.

The roughness of the individual slurry particles in contact with the pad and SiO\textsubscript{2} substrate may affect the frictional forces. The roughness of the materials is measured with atomic force microscopy (AFM). The PU pad has a large pore structure on the order of 10 microns. The AFM is used to image the regions between the open pores to determine the nanoscale roughness of these regions.

CMP scale friction measurements are done using a pin on disk type bench top tribometer. The tribometer has a rotating turntable to which slurry wetted polishing pad samples are mounted and an arm that holds spherical SiO\textsubscript{2} (counterface) samples. A normal load is applied to the arm and load sensors in the arm measure the friction during simulated polishing conditions. A series of baseline experiments will first be performed to isolate the effects of water and KOH solution on the PU pad material friction with the SiO\textsubscript{2} counterface. Next, friction force will be measured in the presence of slurry with varying percentages of SiO\textsubscript{2}.

**FRICTION MODELING**

The friction of the overall counterface (substrate) and PU pad pair is broken down further into three distinct friction force components. The pad-substrate $f_p$, the slurry particle-substrate $f_s$, and the slurry particle-PU pad $f_{sp}$. Each friction component has an associated coefficient of friction, which has corresponding mechanical and molecular adhesion components [2]. The components can be represented in the form, $F = [C_1\mu_p + C_2(\mu_s - \mu_{sp})]P$, where $F$ is the total sliding force, $P$ is the normal applied force, and $C_1$ and $C_2$ are constants representing the number of contacts. Contacts will be estimated by slurry particle density, PU pad roughness distribution, and rough contact modeling [3]. The pad porosity is taken into account for estimation of the contacts.

**CONCLUSION**

It is expected that the PU asperity friction will be a significant contributor to the total CMP scale friction. It is anticipated that this advanced understanding will help in alleviating existing issues in integrating low k dielectric materials, which are sensitive to shear from CMP friction, into next generation IC fabrication processes.

**REFERENCES**