SYMPOSIUM F
Chemical-Mechanical Planarization

April 22 – 24, 2003

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*Invited paper
SESSION F: CMP MODELING
Chair: Michael R. Oliver
Tuesday Morning, April 22, 2010
Golden Gate B3 (Marriott)

8:30 AM F1.1
THREE-DIMENSIONAL WaFER PROCESS MODEL FOR
NANOTOPOGRAPHY. Takafumi Yoshida, VNTJp, Corp, Dept of
TCAD, Hitn, JAPAN.
This paper proposes a three-dimensional wafer process model for
nanotopography. This model allows us to predict the eect and
behavior of inhibitors on the wafer processes especially for the
wafer Mechanical/Chemical Logging (MCL/CLP), wafer
Single/Double Side Polishing (SSP/DSLP) and device Chemical
Mechanical Polishing (CMP).
data which provide greater spatial and temporal resolution of
temperature and film thickness measurements.

10:30 AM Fl.7
NEWS FROM THE M IN CMP - VISCOSITY OF CMP

The viscosity of CMP slurries has an effect on polishing results. Furthermore, it has been acknowledged in numerous publications that the viscosity of these slurries is not always constant but rather can show significant differences after different polishing conditions. While for most calculations in the literature the viscosity is regarded as a constant, the real viscosity of a CMP-slrury varies widely at high shear rates. Typically viscosity measurements are carried out using systems based on a rotating cylinder or a plate. Plate systems can reach a shear rate range up to 50,000 1/sec. The calculation of the shear rate between the wafer and the polishing pad is based on a standard relative velocity of 1 mm/sec and a distance between the wafer and the pad of 20 mm. If parts of the polishing pad come closer to the wafer or even if they come close to the edge of structures on the wafer (for example 1 mm instead of 20 mm) then the shear rate will significantly increase in these regions to values as high as 1,000,000 1/sec. When the shear rate is very high, the viscosity depends mainly on hydrodynamic factors like the viscosity of the solvent, abrasive content, aggregate particle size, particle size distribution and shape of the particles. The characteristic shape of fused metal oxides is controlled during the synthesis in the flame process. The dispersion process also has a significant impact on the performance of these particles in CMP as it is responsible for the particle size distribution, shape of the particles and thus effects the high shear rate viscosity of the slurry. Therefore, the dynamic viscosity of different silica slurries on the surface area, concentration and preparation methods will be shown and the impact on the CMP process will be discussed.

11:00 AM Fl.8
ATOMIC MECHANISMS UNDERLYING CHEMICAL MECHANICAL PLANARIZATION OF COPPER, Y. N. Ye, R. Biavas, Iowa State University, Dept of Physics, Ames Lab & Microsystems Center; A. Bastavros, Iowa State U, Dept. of Aerospace Engg.; A. Chandra, Iowa State University, Dept. of Mechanical Engg.

To understand the fundamental atomic scale mechanisms underlying CMP of copper we have performed molecular dynamics of copper surfaces using the embedded atom model. We have simulated two basic processes of surface planarization consisting of chemical abrasion and chemical dissolution. Mechanical abrasion produces rough planarized surfaces with a large chip (debris) in front of the abrasive period. The addition of chemical dissolution is critical for achieving very smooth planarized copper surfaces, and leads to considerably smaller frictional forces that prevent bulk dissolution.

The material removal rate will be simulated as a function of the strength of chemical dissolution as a function of temperature gradients occurring during the processing conditions, identifying regimes of polishing. Simulation results will be related to experiment.

11:15 AM Fl.9
WAVELET BASED MULTISOLUTION MONITORING OF A NANO-MAChINING PROCESS IN SEMICONDUCTOR MANUFACTURING: Rajesh Ganesan and Tapan D. Das, Department of Industrial and Management Systems Engineering, University of South Florida Tampa, FL; Ashok Kumar and Arun K. Sikder, Nanomaterials and Nano Manufacturing Research Center, Department of Mechanical Engineering, University of South Florida, Tampa, FL.

In response to the demands placed by perpetual changes in technology on advanced manufacturing processes (e.g., nanoscale machining), research on new and improved methods to monitor the needs of such processes. Examples of such needs are: 1) in-situ sensor based monitoring and control, 2) online analysis for real time control, 3) extraction of the process related information hidden in the broad frequency band. The wavelet domain has the capability to handle a wide variety of data. Effective monitoring and control of processes with the above needs is challenging and often impossible using existing methods. In the last decade, wavelet based multiresolution analysis has revolutionized the tasks of signal processing.

However, the scope of wavelet based methods in the fields of statistical applications, such as process monitoring, density estimation, and defect identification is still in their early stages of evolution. Recent literature contains several wavelet based real time process monitoring approaches including many real life process monitoring applications, such as tool-life monitoring, bearing defect monitoring, and monitoring of ultra-precision processes. This paper develops an online wavelet based multisolution monitoring method. The method is then applied to a nanoscale machining process that occurs in chemical mechanical planarization (CMP) step of wafer fabrication in semiconductor manufacturing. The application involves identification of delamination defect of low dielectric layers by analyzing non-stationary acoustic emission (AE) signal and coefficient of friction (CoF) signal collected during copper damascene (Cu-layer) CMP process. The data collected from two different sources representing both in-control and out-of-control conditions were studied. The results show that the wavelet based approach using AE signal offers an efficient means for real time detection of delamination defects in CMP processes. Such an online approach, in contrast to the existing offline approaches, offers a viable tool for CMP process control.

11:30 AM Fl.10
DYNAMIC CONTACT CHARACTERISTICS FOR CMP MODELING: Wonseop Choi, Seung-Min Lee, and Rajiv K. Singh, Department of Material Science and Engineering and Engineering Research Center for Particle Science and Technology, University of Florida, Gainesville, FL.

In CMP, it is critical to understand the dynamic contact characteristics at the interface of pad-particles-wafer for the development of more sophisticated CMP models. The dynamic contact characteristics significantly depend on process variables (plate velocity and down pressure) and particle characteristics (particle size and particle concentration). These variables also affect material removal rate during CMP. In this paper, we present the dynamic contact characteristics at the interface of pad-particles-wafer and the effect of dynamic contact on material removal. For this study, in-situ dynamic friction force measurements were conducted to measure the effect of the dynamic contact as a function of CMP variables. It is shown that the dynamic contact characteristics arise from fluid dynamic models at low particle concentration and is the result of particle based contact model at high particle concentration.

11:45 AM Fl.11
SPECTRAL ANALYSIS OF FRICTIONAL FORCES IN CMP: Arun Philippsan, Leslie Charns and Daniel Roads-Yee,man, University of Arizona, Department of Chemical & Environmental Engineering, Tucson, AZ; Chris Rogers, Tufts University Department of Mechanical Engineering, Medford, MA; Toshihoy Doi, Saitama University Department of Mechanical Engineering, Saitama, JAPAN; Motonari Kishitsuki, Nohdel-Nitta Company, Tokyo, Japan.

Spectral analysis of real-time frictional data obtained during I-IL CMP is used to further elucidate the fundamental aspects of the tribology and material removal rate characteristics of the process in terms of stick-slip phenomena. Fourier transform analysis is employed to quantify the total mechanical energy input to a given CMP process as a function of various IG-1000 pad groove shapes (un-grooved, perforated, XY-groove and K-grooves) and PL-4217 silicon carbide concentrations (2.5e25 percent silicon by weight). Across a wide range of wafer pressures (2 to 6 PSI) and wafer-pad velocities (0.31 to 0.83 meters per second) studied, results indicate that, for a given pad, increasing abrasive concentration from 5 to 25 percent causes a dramatic reduction in the variance (as measured by the amplitude of the wave-function) and the spectral frequency of the force signal. Further increases in abrasive concentration (from 25 to 50 percent) minimally impact force variance and frequency thereby suggesting the existence of a threshold abrasive concentration (presumably between 6 and 9 percent by weight) beyond which stick-slip phenomena are minimized. Pad grooving patterns are also shown to dramatically modulate the variance and frequency of the resulting frictional force signal thus indicating that importance of matching a particular slurry abrasive concentration to a particular groove design for desired polished outcomes. As long as abrasive concentrations in excess of the threshold value are used, removal rate data are shown to strongly correlate to the total mechanical energy input to the system. The latter is also shown to accurately predict the tribological mechanism of the process without the need for derivation and construction of process- and consumable-specific Striebeck Curves.

SESSION F2: CMP SCIENCE
Chair: Denise S. Beving
Tuesday Afternoon, April 22, 2008
Golden Gate B3 (Marriott)

1:30 PM F2.1
ATOMIC FORCE MICROSCOPY STUDIES OF CMP OF INORGANIC MATERIALS: Tom Dickinson, Forrest Stevens, Ryan Leach, and Steve Langford, Washington State University, Pullman, WA.
We present results of fundamental studies of the simultaneous application of chemical and mechanical stresses applied between a model singleasperity and a solid surface. We show the consequences of combining highly localized mechanical stress (due to contact with an atomic force microscope--AFM tips) and exposure to aqueous solutions. The experiment simulates many features of a single particle-substrate-slurry interaction in CMP. In particular, we show quantitative, correlated data on the wear occurring on both surfaces. We examine surfaces of inorganic single crystals, glasses, and silicon nitride, as well as the results on tip induced recrystallization (at small normal forces) and unique patterning produced by scanning in super-arranged aqueous solutions. Finally, studies of exposing polymer surfaces to stress and organic solvents will be discussed. Models are presented to explain these observed nanometer scale surface modifications.

1:45 PM F2.2
AFM APPLICATIONS OF INTERACTION FORCES IN CMP
APPLICATIONS Ivan U. Vaisakh, G. Balasubramaniam, Scott C. Brown, Yakov I. Babkinovich, Baj M. Mardani, Department of Materials Science and Engineering Research Center for Particle Science and Technology, University of Florida, Gainesville, FL.

An atomic force microscope (AFM) was used to simulate the abrasive particles/surface interaction in the chemical mechanical polishing (CMP) process. Lateral force measurements were performed between a silicon particle and a silicon wafer at the presence of surfactant dispersions and exhibited close to the CMP process in our previous study. It was shown that the surfactant dispersions were effective in stabilizing the slurries but yielded minimal material removal. The lateral force measurements revealed the map of the wear rate is due to the boundary lubrication provided by the surfactant residing in between the particles and the wafer. It has been demonstrated that it is possible to manipulate the range in which the boundary lubrication is effective by simply changing the solution conditions of pH and electrolyte concentration. A dramatic increase in the frictional force was observed in the presence of specific counterions. Polishing tests showed high material removal rate with a good surface finish.

2:00 PM F2.3
Abstract Withdrawn.

2:15 PM F2.4
THE EFFECT OF PAD PROPERTIES ON THE PLANARITY IN A CMP PROCESS. Hyoung Kim, Dong-Woon Park, Chang-Ki Hong, Wook-Sung Heo, Joo-Hee Moon, Semiconductor R&D Center, Samsung Electronics Co. Ltd., Yonsei, KOREA.

This study presents the effect of pad properties, such as elastic modulus and surface roughness, on the planarity in a CMP process. A system model of a planarization process, which represents the die-scale planarization in a quantifying manner, has been proposed. It has been shown that the planarization length is highly dependent on the bulk modulus of the pad. The effect of elastic modulus and roughness of the pad on planarization length, which represents the features-scale planarization, has been shown. Dishing amount is determined by the elastic modulus of the superficial layer of the pad, which is typically hundreds of microns thick, rather than by the bulk elastic modulus of the pad. A double layer pad model has been proposed based on the observed results, which can explain that the dishing amount is reduced by increasing elastic modulus of the pad superficial layer, or by decreasing the surface roughness of the pad.

2:30 PM F2.5
MULTI-SCALE CHARACTERIZATION OF ROLE OF THE PAD ON MATERIAL REMOVAL RATE IN CHEMICAL MECHANICAL PLANARIZATION. S. C. Brown, Iowa State University, Dept. of Aerospace Engineering and Engineering Mechanics, Ames, IA; Abhijit Chandra, Srinivasan Dass, Iowa State University, Dept. of Mechanical Engineering, Ames, IA.

The role of porous pad in controlling material removal rate [MRR] during the chemical mechanical planarization (CMP) process has been studied through a combined experimental and numerical study. The visco-elastic response of the pad is evaluated at different length scales ranging from the abrasive particle scale to the macroscopic wafer scale. The pad morphology is also measured and characterized. The measured quantities are utilized to develop predictive numerical and phenomenological models that correlate the forces on each individual abrasive particle to the applied nominal pressure. The models provide physical explanation of the experimentally observed domains of pressure-dependent material removal rates, wherein the pad deformation controls the load sharing between active abrasive particles and direct pad-wafer contact. The predictive correlations between the MRR and the slurry characteristics, (i.e., particle size and concentration), are compared against experimental observations.

3:15 PM F2.6
PAD DEGRADATION DURING CMP PROCESS EFFECT OF SOAP IN SLURRY AND WATER ON THERMAL AND MECHANICAL PROPERTIES OF THE CMP PADS. Alex Tregub, Intel Corporation, Fab Materials Operation, Santa Clara, CA; Grace S. Ng, Massachusetts Institute of Technology, Dept. of Materials Science and Engineering, Cambridge, MA; Mansour Manpour, Intel Corporation, Fab Materials Operation, Santa Clara, CA.

During a traditional CMP process, which involves application of polishing pads and slurries, the pad properties can be substantially and irreversibly changed as the result of slurry fingerprint adsorption. The fingerprint adsorbed on the “hard” and “soft” pads were discovered: diffusion to the hard pads followed Fickian law, while diffusion to the multi layer soft pads was dominated by the fast filling of the highly porous pad surface with liquid. The retention of the pad properties after exposure was monitored using such thermal and mechanical techniques, as Thermal Mechanical Analysis (TMA), Dynamic Mechanical Analysis (DMA), Modulated Differential Scanning Calorimetry (MDSC), Thermal Gravimetric Analysis (TGA). Thermal and mechanical properties of these pads were affected by soak. The most interesting findings are listed below: TMA results for soft pads indicated considerable shrinkage of the pads after soak for four weeks in DI water and water. DMA results for soft pads showed 40% decrease of glassy modulus and 25% decrease of macromolecular mobility after pad soak in slurry for four weeks. MDSC results for hard pads revealed irreversible exothermic reaction in the range of 260°C to 130°C. Heat of this reaction was not affected by soak in water for as long as one month; however, it increased significantly after soak in slurry for two weeks. Correlations between the experimental observations, pad molecular structure, and pad performance in CMP processes will be discussed.

3:45 PM F2.7
INTERFACIAL TRANSFER BETWEEN COPPER AND POLYURETHANE SURFACES. Hong Liang, University of Alaska Fairbanks, Dept. of Mechanical Engineering, Fairbanks, AK; Jean-Michel Martin and Thierry Le Mogne, Ecole Central de Lyon, Lyon, FRANCE.

We conducted fundamental investigation of interfacial interactions between copper and polyurethane surfaces. Using in situ surface analysis techniques we were able to evaluate effects of water molecules on both materials surfaces during rubbing. Results also indicated that hydrogen transfer elements from copper and water due to friction. In this presentation, we discuss a new polishing mechanism.

4:00 PM F2.8
EFFECT OF COFFEE AS A COLEFT AND PROCESS CONSIDERATION ON IILD REMOVAL RATE FOR VARIOUS PADS AND SLURRY ADSORPTION CONCENTRATIONS. Aria Paygazi, Scott Olsen, University of Arizona, Department of Chemical & Environmental Engineering, Tucson, AZ.

This work is based on the premise that during planarization, coefficient of friction (COF) in the polyhedral-asperity region dramatically affect pad life thus necessitating a fundamental understanding and control of the magnitude of forces involved in the process. Given the above postulation, identification of the tribological mechanism and determination of key factors contributing to the extent of pad-slurry wafer contact will be critical. In this work, real time COF analysis, in conjunction with a new method for approximating the Sommerfeld Number is used to determine the extent of normal and shear forces during CMP and help identify the tribology of the system. A total of seven pads with varying surface textures and grooves types, and six slurries with varying abrasive concentrations are used to polish IILD films over a wide range of wear pad velocities and pressures. The results show that the “tribological mechanism indicator” is defined and extracted from the resulting Strubeck curves. The information on COF, “tribological mechanism indicator” and IILD removal rate will be shown. In addition, “universal correlations to help identify polishing conditions for optimized pad life and removal rate. Results further show that high abrasive concentrations, as well as the extent of surface texture and pad grooving, in the latter are incorporated in the Sommerfeld Number indication can dramatically shift the tribology of the system.
be removed by subsequent chemical mechanical polishing (CMP). The conventional slurry-based processing however often leads to strong thinning of the Cu interconnect material. Ultrasonic cleaning and polishing have been demonstrated to improve the smoothness of Cu interconnect materials. UBM processing can be carried out to clarify the advantages of bulk silicon wafers. Surface roughness is a key parameter in this process. CMP polishing removes the remaining Chemical Mechanical Polishing (CMP). The conventional slurry-based processing however often leads to strong thinning of the Cu interconnect material. Ultrasonic cleaning and polishing have been demonstrated to improve the smoothness of Cu interconnect materials. UBM processing can be carried out to clarify the advantages of bulk silicon wafers. Surface roughness is a key parameter in this process. CMP polishing removes the remaining Cu interconnect material.
while the D99 affects the surface roughness and the degree of microcracks. Shurries with similar D50 and varying D99 showed insignificant results. However, a component that provides selectivity between oxide and nitride to the shurry resulted in an increase in their oxide rate differential. It was observed that the number of particles at a given particle size, and not just D50 and D99 needs to be considered to define the shurry. A term defined as Particle Count Identifier (PCI) is introduced here that provides a comparative gauge to evaluate the number of particles in tail and main and hence define the distribution more accurately.

9:15 AM F3.3
INTERACTION BETWEEN CERIA AND HYDROXYLAMINE.
SubrahmanianTamizhmani, Wayne Hung and Srinivasan Subrahmanian
Department of Materials Science and Engineering, University of Arizona, Tucson, AZ, Robert Smith and Brandon Scott, EKC Technology, Inc., Hayward, CA.

Ceria containing slurries are increasingly used in the chemical mechanical polishing of CVD silicon oxide films to obtain STI structures. Unlike silica or alumina, ceria has redox characteristics. Because of this characteristic, removal of ceria particles from planarized surfaces may be possible using chemical reagents that can participate in redox reactions. One such reagent is hydroxylamine, which is already being used in copper CMP. The objective of the work reported in this paper was to characterize the reaction between ceria and hydroxylamine, especially with respect to dissolution of ceria particles. A kinetic study of the dissolution of ceria in hydroxylamine solutions maintained at various pH values has been performed. The extent and kinetics of ceria dissolution have been determined by ICPMS. Removal of ceria particles from oxide surfaces using hydroxylamine-based chemistry has been investigated.

10:00 AM F3.4
UNDERLYING DEFECT MECHANISMS IN FUMED SILICA SLURRIES. Sarah Lane, Nichole Bishop, Tim Mace, and Brian Mueller, Rodel, Inc., Newark, DE.

Polishing ILD with fumed silica dominates the volume of total CMP slurries sold and ILD polishing perceives in the integration schemes to <0.065 mm on manufacturers roadmaps. As devices scale smaller, the key metric that is critically tied to the shurry is defectivity. The roadmap addresses defect type, threshold size and concentration. The call to arms for shurry R&D groups intent on developing the next generation ILD slurries is "reduce microcracks." This is challenging for R&D efforts because the successful development requires advances in particle science, dispersion technology, chemistry and metrology. To develop improved ILD slurries, many companies have simplified the solution to the problem of the creation of slurries with reduced large particle counts (LPC's) arguing that large particles cause scratches. Indeed, advanced filtration has typically lowered LPC's and improved defectivity. However, there seems to be a limit to the benefit of lower defectivity obtained through reduced LPC's and filtration. This paper attempts to dig further and to identify the underlying causes of microcracks, to show how advanced processing can ultimately lead to an improved ILD shurry. We will break down potential mechanism of microcracks and identify experimental evidence, the potential root causes. We will then tie improvements in our ILD shurry to these root causes, making the case that there will be a reduced number of microcrack "events" with this new shurry during polishing. We will conclude with a description of our defect review methodology in representing the specific attributes of an improved ILD shurry to defect type and characteristiques.

10:15 AM F3.5
THE STUDY OF PARTICLE ADHESION FOR CHEMICAL MECHANICAL POLISHING USING PACKED COLUMN TECHNIQUE. Zheng Li, Egon Motiejec and S.V. Bhoj, Department of Chemistry and Chemical Engineering, Center for Advanced Materials Processing, Clarkson University, Potsdam, NY.

The properties of abrasive particles, and their interaction with surface films to be polished play a key role in chemical mechanical polishing (CMP). This study applies the packed column technique to the investigation of the chemical/ mechanical forces at particle/ film interface in the presence of different slurry chemistries. Well-defined suspensions of particle, including spherical silica and silica cores coated with nanosized ceria particles, as well as calcined alumina particles were used to study particle adhesion on copper and glass beads. It was shown that pH and slurry flow rate had significant effects on particle deposition and detachment. The deposition results of silica particles on copper beads in the presence of H2O2 of various concentrations had a strong correlation to the removal rate of copper films. Furthermore, the deposition of alumina particles on copper beads at different pHs did not have a significant effect to the removal rate of Cu films.

10:30 AM F3.6
ENGINEERED NONPOROUS SILICA PARTICLES FOR LOW DEFECTIVITY IN LOWk DIELECTRIC CMP. K.S. Choi and R.K. Singh, Department of Materials Science and Engineering and Engineering Research Center for Particle Science and Technology, University of Florida, Gainesville, FL.

The abrasive particles in the chemical mechanical polishing (CMP) slurries play a critical role in controlling the yield of semiconductor devices. The state-of-the-art CMP slurries employ hard abrasives such as alumina or silicon which can lead to the significant surface defects during polishing. These surface defects during CMP are serious problems for the integration in interconnect structures. To reduce the surface defects, a new shurry design is required. We have studied the nonporous silica particles which are expected to reduce surface defects in low-k dielectric CMP process. By controlling the particle size and porosity, the surface properties of the particles can be effectively modified. Using these particles in the CMP process, we can reduce defectivity in low-k dielectric polishing. For this work, the spherical nonporous silica particles with controlled particle size and surface porosity have been prepared by a precipitation technique. The interaction between the shurry particle and wafer substrate has been investigated by direct force measurement of AFM. We also have inspected the surface defects of wafers polished in nonporous silica particle based shurry systems under AFM and SEM.

10:45 AM F3.7
NANOSCALE AND MICROSCALE MODELING OF CHEMICAL MECHANICAL POLISHING IN METALS AND DIELECTRIC SYSTEMS. Rajiv Singh, Materials Science and Engineering, University of Florida, Gainesville, FL.

Although the Preston’s Equation has been widely to model CMP processes, it has several fundamental flaws which limit its applicability in the process. Firstly it takes into account only mechanical polishing effects, and secondly it fails to provide an insight into the CMP polishing mechanisms. More elegant approach to understand the affect of the process variables is to determine the microscale and nanoscale effects that occur during CMP and correlate this with the output parameters namely the removal rate, planarity and selectivity. This talk will focus on the mathematical model developed using this approach and validated with the experiments conducted on silicon and metal (copper and tungsten) polishing. The effect of various parameters such as particle size and concentration, chemical concentration, polishing pressure and relative velocity have been determined theoretically and experimentally validated.

SESSION F4: IN-ROOM POSTER
Wednesday, April 23, 2013 11:00 A.M.
Golden Glee 3B (Marriott)

F4.1
MODELING OF CMP ON A LOCALIZED SCALE. Shelley R. Gillis, C. Barry Carter, University of Minnesota, Dept of Chemical Engineering and Materials Science, Minneapolis, MN.

A small lab-scale apparatus has been developed for systematically testing the chemical-mechanical planarization (CMP) process. This instrument has the advantage of being small with precision controls, uses minimum amounts of materials (both glass specimens and abrasive materials) and produces specimens that are immediately ready for analysis. To efficiently study the interaction between CMP abrasives and glass or glass-ceramic work pieces the variables in the polishing process such as pressure, velocity, removal rate, finish, subsurface damage and shurry chemistry must all be tractable and controllable. Often when polishing on larger scale machines (12 inch platters and larger) the ability to control variables becomes difficult and often not cost effective. For example, polishing pads are expensive and change over the course of being used. This change in the pad morphology and its amount of abrasive loading can affect the reproducibility of polishing data. In comparison, this instrument requires only a 10 cm² polishing pad, allowing a new pad to be changed at the first sign of wear without being concerned by the cost. In the present instrument, a 3 mm glass piece is rotated about a vertical axis while the polishing wheel rotates on an orthogonal horizontal axis. This apparatus produces a dimple-like depression during the polishing process, which is used to accurately measure the material removal rate. This is accomplished by measuring the depth and width of the dimple by visible-light microscopy. Due to the small scale nature of this equipment no shurry recycling is needed and polishing can also be carried out using a fixed abrasive pad. This system facilitates the immediate characterization of a specimen surface by atomic force...
microscopy, scanning electron microscopy or secondary ion mass spectrometry, and specimens can be ready for characterization by transmission electron microscopy by being cut to a point of perforation. The experimental setup and operation of the instrument for small-scale CMP is illustrated with the polishing of silicate glasses and glass-ceramics with both slurries and fixed abrasives.

**F5.2**

**CO_E2 SLURRIES FOR CHEMICAL MECHANICAL PLANARIZATION**

Xiaogang Feng, Robert Y. S. Her, Wei Zhang, and Jackie Davis, Femto Corporation, Independence, OH.

Chemical-mechanical polishing (CMP) slurries are used, for example, to planarize surfaces during the fabrication of semiconductor chips. CMP slurries contain soluble chemical agents and abrasive particles dispersed in a liquid carrier. The abrasive particles perform a grinding function when pressed against the surface being polished using a polishing pad. It is well known that the size, composition, and morphology of the abrasive particles in a CMP slurry have a profound effect on the polishing rate. Over the years, CMP slurries have been formulated using abrasive particles formed of, for example, aluminum (Al2O3), ceric oxide (CeO2), iron oxide (Fe2O3), silica (SiO2), silica carbide (SiC), silicon nitride (Si3N4), tin oxide (SnO2), titania (TiO2), titanium carbide (TiC), tungstic oxide (W2O5), yttria (Y2O3), zirconia (ZrO2), and combinations thereof. Of these oxides, ceric oxide (CeO2) is the most frequently used abrasive in CMP slurries for planarizing semiconductors because of its high polishing activity. A method is developed to synthesize nanosized Cerium Oxides and its composite particles in the size range of 5 to 100nm for use in CMP applications. It involves the formation of a uniform clear solution containing cerium oxide and its components. This uniform solution is then made into a gel-like material through introduction of bases such as ammonium water. These gel-like materials were then broken down into small particles by rapid stirring or sonication and aging at certain temperature and duration. The particle sizes of the resulting CeO2 or CeO2-composite particles depend on the initial elemental concentrations of Cerium and solution pH. The effect of reaction duration seems to have little effects on particle size of synthesized particles. The temperature effects on size were moderate. These CeO2 composite particles showed good selectivity, excellent surface quality, and desirable polishing rate during CMP tests.

**F5.3**

**ANALYSIS OF CERIA ABRASIVES BY EELS IN AN FETEM**

Shelley R. Gilles, C. Barry Carter, University of Minnesota, Dept of Chemical Engineering and Materials Science, Minneapolis, MN; James Bentley, Metals and Ceramics Division, Oak Ridge National Laboratory, Oak Ridge, TN.

Cerium oxide (ceria: CeO2) is one of the most widely used abrasives for the planarization of silicon glass. Extensive work has been done on the characterization of ceria abrasives. Inductively coupled plasma chemical analysis, surface area analysis, and zero-potential characterization is just a few of the many techniques employed to characterize an abrasive. Typically, chemical analysis of ceria abrasives constitutes a method that describes the chemical species contained in a bulk sampling of the material without a spatially resolved understanding of the composition. Ceria abrasives have been investigated using electron energy-loss spectroscopy (EELS) in a field-emission gun transmission electron microscope (Philips CM30 FEG). By using this technique, EELS in STEM, one can image a specimen and collect chemical information at a specific point with a nanometer sized probe. Analysis shows that abrasives vary in homogeneity and composition. One abrasive may be composed of individual oxide particles containing just La2O3 or just CeO2 whereas another abrasive may be homogeneous in its distribution of cerium, but can vary in F content and the amount of Pr in each individual particle. Individual particles of silica and alumina (likely added as fillers) are also detectable by this technique.

**F5.4**

**SESSION F5: CMP TOPICS, INCLUDING NOVEL DEVICES**

Chair: Kurt Dziki

Wednesday, Afternoon, April 23, 2003

Golden Gate B3 (Marriott)

**13:00 P.M. F5.1**

**SLURRY ADHESION AND ITS EFFECT ON POLISHING**

David R. Evans, SHARP Laboratories of America, Inc., Camarillo, CA.

There are a number of process parameters available for modification and optimization of chemical mechanical polishing processes. Of these, some, such as polishing pressure and substrate-pad relative velocity magnitude, are easily varied both continuously and systematically provide a ready means for process optimization. Moreover, recent enhancements in hardware design allow not only changes in overall polishing pressure, but also control of pressure distribution across a polished substrate as well. Of course, other parameters of the polishing process are not so easily varied. In principle, one would like to hold such parameters strictly fixed and then optimize the process using easily varied parameters. In practice, parameters such as pad wear and texture do not remain fixed and drift slowly over time. In this case, overall pressure and pressure distribution may be changed to compensate for this behavior in order to maintain acceptable process performance. It should be obvious from the preceding remarks that conventional polishing process variables tend to be both coupled and indirect. In the present case, one might argue that the net rate of slurry admission or the effective volume of slurry between the substrate and pad is a more direct process parameter, which is affected by polishing pressure, substrate-pad relative velocity and various other parameters. In this work, the role of slurry admittance is investigated by direct control of interference between the pad surface and the carrier retainer ring. Both fixed and dynamic implementations are investigated. Measured patterns of material removal on substrates polished with a fixed orientation are correlated and discussed.

**1:45 PM F5.2**

**DETERMINATION OF THE EXTENT AND IMPACT OF FLUID DYNAMICS TRANSIENTS AND NONIDEALITIES DURING 30 SECOND PLANARIZATION PROCESSES**

Arnaud Guinand, Erin Mitchell, University of Arizona, Department of Chemical & Environmental Engineering, Tucson, AZ.

Understanding the extent of process transients and flow nonidealities during CMP is critical as film thicknesses and polish times continue to decrease in accordance with the International Technology Roadmap for Semiconductors (ITRS). As such, determining the average time it takes for fresh incoming fluid (slurry, water, or other active agents) to displace the existing fluid in the wafer-pad region is expected to yield critical information regarding fluid concentration near the wafer. Information of this nature is vital since slurry concentration, and its dependence on polish time, is critical in process kinetics modeling. Also, the effectiveness of water, or an active agent, in uniformly displacing the slurry during subsequent rinse (or multi-step polishing) intervals can be compromised if the process is governed by transient effects and severe flow nonidealities. By employing classical Residence Time Distribution techniques coupled with vessel dispersion models for non-ideal reactors, this study quantifies, in real-time, the extent of slurry concentration gradients for 30-second polishing processes as a function of slurry flow rate, wafer pressure and pad-wafer velocity. The study also computes the relative ratio of slurry transport by diffusion to forced convection in order to quantify the extent of mixing in the pad-wafer region. Results indicate that, depending on operating conditions, CMP systems exhibit reactor characteristics ranging from plug-flow to near turbulent. This information is shown to be critical in ensuring uniform fluid distribution across the wafer-pad region. Additionally, a novel method is developed to demonstrate the effectiveness of a new dimensionless parameter, the "Turnover Ratio", which expresses the ratio of residence time (a fluid dynamics indicator) to polish time (a process parameter). A strong correlation is observed between Turnover Ratio and ILD removal, whereby removal rate is shown to vary by as much as 50 percent depending on the Turnover Ratio. Several case studies are reviewed which demonstrate the utility of assessing appropriate values of Turnover Ratio in order to optimize process performance and cost of ownership.

**2:00 PM F5.3**

**SLURRY DEVELOPMENT FOR Cu/ULTRA-LOW-k CMP**

Hugh Li, Mint Vahnheum, and John Quanci, Rodel Inc., Newark, DE.

Conventional CMP for Cu/ULtra-low k (k<2.4) integration faces significant technical challenges. The majority of ULK materials are made porous to reduce the dielectric constant, while trading off on the mechanical strength. With diminished hardness, elasticity and adhesion, the CMP process has to be "kindler and gentler": lower down force, lower relative velocity, softer pad, and slurry with lower abrasive content. In a word, the mechanical portion of the planarization process would be greatly reduced. To maintain the same performance, one has to rely on the chemical reactions to make the Cu/ULK CMP a viable process. In addition to the fragile nature of these ULK materials, topography correction becomes very important as more metal layers are built up to achieve the required yield. Without topography correction, residual metal and depth of focus at upper layers become formidable threats to final yield. Therefore, it is desirable to design adjustable removal rates into the Cu/ULK CMP process to control the thickness of the variety of ULK materials, the Cu/ULK integration schemes also
differ, creating the need for tunable selectivities in the CMP slurry design. In developing barrier slurries for Cu/LK CMP, we considered both mechanical (frictional) and chemical (surface) selectivities. Since film delamination is essentially an adhesion breakdown, the shear stress was estimated by measuring the in-situ frictional force during polishing, which in turn guides us in slurry design. To compensate for diminished mechanical force and to obtain tunable selectivities, chemically active ingredients are added in the slurry to independently enhance and control material removal rates. After development of surface response models, it is possible to quickly find a slurry formulation for a specific integration scheme.

2:15 PM E3.4
COPPER CMP USING ABRASIVE FREE POLISH ON ORBITAL AND ROTATIONAL PLATFORMS. Thomas Lauren, Ismael Enmashe, Ben Palmer, Brian Mueller, Sakte Chadda, SpeedFan/PIMEC, Chandler, AZ

Abrasive free polish (AFP) has gained acceptance as an alternative to slurries using conventional abrasive slurries in the polishing of copper because it enables excellent planarization with low dishing, erosion and oxide loss. The AFP process has been straightforward to implement on orbital polishes in which the possibility of removing reactive polysilicon is high, thereby requiring high-pressure CMP processes, which are required for polishing wafer containing low-dielectric materials. In contrast to this polishing behavior on orbital tools, substantial polishing rates on rotational tools are not typically observed, especially on topographic features or above those 3 phi. This paper covers polishing studies using the abrasive free polish on both an orbital polisher and tools showing that both platforms in reality obey the same Prestonian relationship. This result provides the basis of making a new market that explains the apparent difference in Prestonian behavior.

2:30 PM E5.5
LOW STRESS CHEMICAL MECHANICAL POLISHING OF COPPER/Low K BASED INTERCONNECTS. Rajiv Singh, Seung-Mahn Lee, and So-Ho Jung, University of Florida, Department of Materials Science and Engineering, Gainesville FL; Deepika Singh, Simon Inc; Gainesville, FL

With the rapid deployment of soft materials such as copper and low K dielectrics in back-end processes, concerted efforts have been directed towards novel slurries that can overcome the challenges in the typical CMP system. Traditional slurry systems typically contain hard abrasive materials, which can create a large number of defects such as adhering particles, scratches on the wafers, high shear and normal stresses, delamination of the dielectric and pattern dependent surface topographical defects such as dishing, erosion and dielectric loss resulting from poor slurry selectivity and slurry planarity. Additionally issues related to long-term stability, two-component mixing, effectiveness, and other characteristics in the slurry and the need for sophisticated slurry handling equipment results in significant variations in the CMP performance and higher manufacturing costs. To overcome these issues, sophisticated polishing slurry formulations have been developed which decrease the size of the polishing processing window for optimal results. This focus of this talk is the development of novel low stress CMP slurries to overcome most of the outstanding issues summarized earlier. By using “soft” gentle slurries, the defects of particle and erosion are mitigated and size and use are significantly enhanced. By using specific chemistry the shear and normal stress during polishing can be significantly decreased. The talk will focus on some of the characteristics obtained by these slurries.

3:15 PM E5.6
INTERPLAY BETWEEN pH, OXIDIZERS, CORROSION INHIBITORS AND CHELATING AGENTS ON THE CHEMICAL MECHANICAL POLISHING (CMP) PROCESS MECHANICS. Jay Jagannaray, Seagate Research, Pittsburgh, PA; Udaya Patri, Clarkson University, Potsdam, NY; and Earl Johns, Seagate Research, Pittsburgh, PA.

Chemical mechanical planarization has found extensive use in the fabrication of Thin Film Magnetic Heads. While the basic Thin Film Head (TFH) planarization process principles remain the same, TFH CMP differs vastly from conventional chemical mechanical planarization (CMP) processes in terms of substrate and stack film materials and thicknesses, film properties, process design rules and process metrology. Binary and ternary magnetic alloys based on Cobalt, Nickel and Iron are widely used in the finished head stack structure. The development of CMP slurries for the above magnetic materials that provide good removal rates, planarity, polish uniformity, excellent surface finish and tailored selectivity is key to enabling TFH CMP technology. Unfortunately, very little is known in terms of the electrochemical interaction of these alloys with the various CMP slurry constituents such as pH, oxidizers, passivators, etc. In this study, we elucidate the interplay between the different slurry characteristics, pH, oxidizer concentration, chelating agent concentration, corrosion inhibitors and polish velocity on the polishing characteristics of Cobalt and Iron. For this purpose, detailed potential/dynamic measurements were conducted under dynamic (polish) and static (airgap) conditions. The results of these measurements are correlated with weight loss studies, as well as the predictions from Pourbaix diagrams.

3:30 PM E5.7
CMP REVISED FOR THE MEMS / FOUNDRY ERA. Lawrence Camerletti, Jazz Semiconductor, Inc., Newport Beach, CA.

Foundry driven modularization of process flows within increasing demands for internal and external SOC/MEMS compatibility have made it necessary to extend mainstream dielectric CMP modules outside of their typical usage. Interconnect material requirements, integrated and non-integrated MEMS requirements, post metal Cu inductors atop 6 um metal terminal reference plane implementation and general MEMS friendly polishing has required a "regression" from the more glamorous abrasive free, low-k, in-situ wiring CMP process technologies. None-the-less, characterization of these modified CMP processes can often solidify or generate re-assessment of many engrained CMP process integration (degree of planarization, uniformity, removal rates, through-gate) assumptions. Sputtering removal budgets as a function of topography, pattern density, and feature size distributions are seen to change planarization distance assumptions in the light of dimplification blocking layers, ultra thin film control, passivation / dielectric formation processing of designs or above 3 phi. This paper covers polishing studies using the abrasive free polish on both an orbital polisher and tools showing that both platforms in reality obey the same Prestonian relationship. This result provides the basis of making a new market that explains the apparent difference in Prestonian behavior.

3:45 PM E5.8
TRIBOLOGICAL CHARACTERIZATION OF POST-CMP BRUSH SCOURING. Arn Philippous, and Laked Moustapha, University of Arizona, Department of Chemical and Environmental Engineering, Tucson, AZ.

Brush scouring for post-CMP cleaning applications involves direct contact between a soft PVA brush and the surface of the wafer. As such, the magnitude of frictional forces between the wafer and the brush relative to the magnitude of adhesion forces between particle and wafer, and those between particle and brush must be considered. A V-PWA brush scouring model is constructed for studying the tribology of post-CMP cleaning processes using real-time coefficient of friction (COF) analysis. Results, presented in form of COF as a function of Sommerfield Number, indicate that applied brush pressure has pronounced effect on process tribology and the magnitude of COF. At high to moderate pressures, the tribological mechanism is that of "mixed lubrication" whereas increasing brush velocity causes a dramatic reduction in COF in accordance with classical tribological arguments. At lower pressures the tribological mechanism shifts to "hydrodynamic lubrication" with COF exhibiting values that are an order of magnitude lower than those at high pressures. As pH of the cleaning fluid is increased from 1 to 9, the tribological mechanism shifts from "mixed lubrication" resulting in more than one order of magnitude drop in COF. Results are explained by considering the surface chemistry of the wafer and the brush in response changes in pH. When brush rotation is coupled with brush oscillation, COF increases by an order of magnitude over the range of brush rotational velocities investigated. The tribological mechanism and the causes of such a phenomenon are currently being investigated. The above data underscores the importance role tool kinematics plays in customizing the magnitude of shear forces exerted by the brush on the wafer and illustrates how various kinematic and mechanical parameters can be used to "fine-tune" the shear forces involved in brush scrubbing. Above trends continue to hold for different types of PVA brushes. Differences among various types of PVA brushes are explained by considering surface texture, compliance and overall surface area of the nodules. Additionally, Fourier analysis of the frictional force resulting from various operating conditions is shown to be a valuable tool in understanding and interpreting the experimental data.
PLANARISATION OF PATTERNEADMAlUMINA/DIAMOND SURFACE FOR SAW DEVICES. G.K. Reeves and A.S. Holland, School of Computer Systems Engineering, RMIT University, Melbourne, AUSTRALIA; P.W. Leech, CSIRO CMST, Clayton, AUSTRALIA.

A novel method for forming interdigitated electrodes for GHz SAW devices on diamond using a damascene-like polishing technique is described. Low aspect ratio Al electrodes are released into the diamond substrates to create a new planar surface. This allows the deposition of higher quality oriented ZnO. However, the released Al electrodes required here are significantly more difficult to fabricate than the higher aspect ratios (1-5) encountered in IC interconnects. For low aspect ratios, the problem of ‘hollowing out’ of the Al during planarisation presents a serious difficulty for both the electrode regions and the pad-interconnect regions where lateral dimensional control is encountered. This is a well-recognized problem. To overcome these problems, the author proposed to create a planar surface in the electrode region of the SAW device and (b) to minimize the removal of the metal in the pad-interconnect area of the SAW. Substrates (1cm x 1cm) of commercial CVD diamond (20µm thick) on Si wafers were ion-beam etched with trench widths in the range 1.5mm to a depth of ~80µm. (For 1µm widths, the diamond trench aspect ratio is 0.08). Aluminium (120µm thick) was sputter-deposited onto the etched diamond and was polished using either (i) a solution of 0.05µm silica on a neoprene polishing cloth (Stemms SP-PoliCell) or (ii) using a ~0.1µm thick Teflon pad with colloidal solutions of 0.05µm or 0.02µm silica. Using AFM scans and optical profilometry it was observed that the combination of method (i) with the small sample size resulted in significant hollowing-out of the Al electrodes and complete removal of Al from over 90% of the pad-interconnect area. The alternative technique in (ii) demonstrated far less Al relief and surface uniformity in the electrode patterns. There was only marginal improvement when using 0.05µm silica instead of 0.02µm silica. SAW devices have been successfully fabricated and tested on the recessed electrode substrates. [1] A. S. Holland, G.K. Reeves, and P.W. Leech, "Uniformity ofdamascene ZnO on a lithographically patterned metal/diamond substrate," Proc. Sp. MRS vol. 672, pp. 08.21-1-6. April 2001.

THE DEVELOPMENT OF A DIRECT-POLISH PROCESS FOR STI CMP. Antonella Martin, Giulia Spinolo, Sonia Morin, Maurizio Bacchetti, Francesca Francig, ST Microelectronics, Agrate b. ITALY; Maurizio Trienulis, Applied Materials Europe, Agrate, ITALY; Benjamin A. Bonner and Peter McKee, Applied Materials, Santa Clara, CA.

Chemical mechanical planarisation (CMP) of shallow trench isolation (STI) structures continues to be an area of intense research. In recent years there has been a lot of research aimed at performing STI CMP that does not depend upon reverse mask and/or tiling to alleviate problems created by density differences. Terned direct polish, this would allow for a simpler process flow with lower cost, but must still achieve the same or better on-wafer performance. The current study involves the development of a direct polish for STI CMP on 200mm wafers at 1215mm technology node. Two different direct polish processes were developed, both using high-silicoyt for reduction (HSS). The final and initial direct polish processes show an overall cost reduction of 77% and 56% compared to reverse mask, respectively. The final-only in production to key performance factor for post-CMP STI wafers is the uniformity of the remaining silicon nitride. Pilot production data from the final direct polish process with the HSS reached in a range of 2.4um range, while the reverse mask resulted in a 1.9um range across the 200mm wafer. Direct polish processes on multiple polishers using industry standard silicon slurries have post-CMP silicon nitride ranges of 1.4 to 1.6um. Dishing (excess removal of silicon oxide in non-active area) is another key performance factor in STI CMP. The final and initial HSS direct polish processes have 77% and 84% reductions in the dishing range, versus the reverse mask process, respectively. Comparisons of dishing to step height post-CMP and post-silicon nitride will be made. Microscratch results from all three processes have been thoroughly characterized and will be reported. Cross-sectional SEMs after CMP and after removal of the silicon nitride will show the final planarisation achieved after direct polish.

SESSION F6: COPPER AND BARRIER SLURRIES

Friday, April 7, 2003
Golden Gate E3 (Marriott)
8:30 AM #F6.1 SUPRAMOLECULAR ABRASIVE-FREE SYSTEM FOR Cu/SILK CMP. Jason Kelcher, Kenneth Rushing, Yushu Li, Center for Advance Materials Processing, Department of Chemistry, Clarkson University, Potsdam, NY; Bill Wojtczak, SACHEM, Austin, TX.

Key issues in CMP today include reduction of surface defectivity and enhancement of planarisation efficiency. More specifically, the polished surface should be free of defects such as scratches, pits, corrosion spikes, and residue particles, and corrosion. For copper CMP, one of the most promising strategies to accomplishing these goals is an Abrasive-Free Process (AFP). By eliminating abrasive particles from the process, either free or fixed to the pad, it has been shown that corrosion defects such as active corrosion, particle contamination and sharry instability via particle aggregation or settling will be significantly reduced. In addition, with proper formulation, an abrasive-free process can yield an excellent over polishing window and desired step function of pressure for material removal rate. Coupled with a supramolecular design, some of the characteristic advantages seen in abrasive contain system such as step height reduction efficiency can be realized without the side effects often found with abrasive products. In this study, some designating principles for an abrasive free system will be first presented. The potential advantages of a supramolecular design for the low k integration will be illustrated. The CMP performance on a set of testing blanks and patterned wafers will be discussed.

9:00 AM #F6.2 ELECTROCHEMICAL MEASUREMENTS DEMONSTRATE PERFORMANCE OF BITAH AND ALTERNATE PASSIVATING AGENTS ON COPPER IN A HYDROXILAMINE CMP SYSTEM. Melvin Keith Carter and Robert Small, EKC Technology, CMP Engineering, Hayward, CA.

Benzotriazole (BTAH) is an important chemical compound used nearly exclusively for passivation of copper in CMP processing. BTAH is a relatively aggressive passivant, and is able to protect the copper surface and impede intermetallic contacts to copper, and ILD cap layers. Extensive studies of benzotriazole (BTAH) as a copper passivating agent have shown the primary monolayer forms on copper surfaces followed by a build up of secondary layers. Two groups have shown the primary Cu-BTA layer lies flat on the copper surface while subsequent layers stand on edge. Metelko-Hukovic et al demonstrated formation of the Cu(I)-BTA complex on copper surfaces. Other work has demonstrated the thickness of the secondary layer depends on the concentration of BTAH and time of exposure. This current study employs a new type of electrochemical measurement demonstrating rapid formation of the primary monolayer, contrary to the report by Ein-Eli et al, and slower formation of secondary layers of a bi-layer passivation.

Electrochemical data is reported for organo passivating (chelation/ad sorption) agents BTAH (see inset), ammonium salicylate, malonic acid, malonic acid and 3-methyl-2-benzimidazole during abrasive free CMP (chemical mechanical planarisation) of copper coated silicon wafers as possible replacements for BTAH. Measurements conducted in 1.25M hydroxyamine sulfate at pH 3.5, 5, and 7.5 produced passivation times of 150s, 15s, and 3s respectively as well as pre-breakdown times and re-growth times during timed pad contact, pad withdrawal cycles providing voltage traces demonstrating bi-layer passivation. Passivation factors are reported comparing the performance of tested compounds with BTAH on copper.


9:15 AM #F6.3 SELECTIVITY STUDIES ON TANTALUM BARRIER LAYER IN COPPER CMP. Arun Vijayan Kumar, Tianhao Du, Kalpathy Sundaram, Vimal Devi, University of Central Florida, Advanced Materials Processing and Analysis Center, Orlando, FL.

Copper metallization in sub-0.18 mm semiconductor devices is achieved by combining the dual damascene techniques followed by chemical mechanical planarisation (CMP). Tantalum and its nitride have been identified as the diffusion barrier layer for copper metallization. However, the wide differences in properties between copper and tantalum layers results in selectivity problems during CMP process. Differences in chemical and physical properties between copper and tantalum lead to variations in removal rates, which may result in dishing during CMP. Therefore a two-step polishing process is utilized to obtain good planarity. The aim of this work was to gain a better understanding on the sharry selectivity for copper and tantalum and to develop slurries with better selectivity performance. In this work, the effect of several chemical parameters (abrasive type, pH, density, concentration, pad, etc) etc on static and dynamic tests using advanced electrochemical techniques and surface analysis techniques. Polishing experiments are carried out on metal
Copper chemical mechanical planarization (CMP) is one of the most important techniques for damascene and dual damascene interconnect processing. The demand for copper CMP slurries that can provide high polish rates and fewer defects has led to the integration of Copper and Low-k dielectrics. This makes Copper CMP more to be a chemistry-driven process rather than a mask-driven process. The most important parameters in determining the performance of the chemical components in the slurry. We investigated the role of several organic acids including glycine and citric acid, as complexing agents in hydrogen peroxide based slurries and correlated their chemical properties with the material removal rates and defect formation. Copper dissolution and polish rates and in situ electrochemical experimental results at various concentrations of the complexing agents and various pH values will be presented. It has been observed that the ability of the complexing agents to form stable soluble complexes in DI water, the dissolution constant of the complexing agents and the pH of the slurry not only affect copper removal rates but also the type of defects formed during CMP. In the absence of inhibiting agents in the slurry, high polish rates, aggressive pitting and fewer scratches are observed at low pH values whereas low polish rates and aggressive scratching are observed at high pH values. Hence, it appears possible to minimize defects by an appropriate choice of complexing and inhibiting agents as well as pH and other process parameters.

11:30 AM P0.8

Chemical mechanical planarization (CMP) for copper damascene patterning is commonly performed in two main steps. The first step removes the bulk of the copper in a high-rate process, while the second step removes either the line alone (selective) or the remaining copper and the liner in the field region (possibly the ILD and comparable rates (non-selective). Inherent problems associated with the damascene patterning process are copper line dishing, ILD erosion, and CMP-induced defects, which can reduce the IC performance, yield and reliability. Various commercial and experimental slurries (with aluminum or silicon abrasives) have been evaluated for dishing, erosion and post-CMP surface quality using single-level damascene patterns on 25 and 300 nm silicon wafers. Typically, PVD copper, Ta liner and oxide ILD are used, although some results are also obtained with CVD copper, CVD TaN liner and oxide ILD (latter focused on via fill applications). Dishing values as low as 50 nm in 200 nm wide features, ILD erosion as low as 20 nm and good die uniformity have been achieved with non-selective second step slurries; comparable, but slightly worse, performance is obtained with selective second step slurries. These slurries are characterized for particle size and select potential with capillary hydodynamic fractionation (CHDF) and electrostatic amplitude (ESA) techniques. Correlation of slurry properties with damascene patterning metrics will be presented and discussed.

11:30 AM P0.9
POLISHING BEHAVIOR OF INTERLAYER FILMS IN Cu DAMASCENE PROCESS WITH DIFFERENT BARRIER AND Cu SELECTIVE SLURRIES. A.K. Sidde, University of South Florida, Center for Microelectronics Research, Tampa, FL; Pushparaj Zante and Ashok Kumar, University of South Florida, Department of Mechanical Engineering and Center for Microelectronics Research, Tampa, FL.

Chemical Mechanical Polishing (CMP) is a key technology for Cu damascene wire processing in integrated circuit (IC) manufacturing. Experiments on wafer may be exposed to 15 or more CMP steps before final device assembly. Understanding the basic of CMP process is critical for successful implementation of this process in sub-0.35 micron technology. Also it is important to understand the effects of chemical and tribological properties of the interlayer coatings on the CMP process in order to successful evaluation and implementation of these materials. In this paper, we present the mechanical and tribological properties of different interlayer coatings (SiOx, SiC, B, low-k C, SiLK, Cu) and describe the CMP process using different selective Cu and barrier slurries. Mechanical properties were evaluated by the nanoindentation technique. A micro-CMP tester was used to study the fundamental aspects of CMP process. The coefficient of friction (COF) was measured during the process and was found to decrease both with down pressure and with polish rate. An acoustic sensor, attached with the substrate
THE COMBINATORIAL INFLUENCE OF INHIBITORS AND COMPLEXING AGENT IN Cu CMP. Ying Luo, Tianbo Du, Visual Design, Advanced Materials Processing and Analysis Center, University of Central Florida, Orlando, FL.

Copper is regarded as the material of choice for interconnects in integrated circuits (ICs) manufacturing due to its low resistivity and high-electrical conductivity. Incorporation of copper in Cu plating process can be accomplished by using the dual Damascene technique, in which chemical mechanical polishing (CMP) technique has been applied to remove the overburden material and planarize the wafer surface. This study aims to improve our understanding of the removal mechanism during copper CMP using hydrogen peroxide-glycine based slurries under the influence of various inhibitor and complexing agents at various pH (2 to 10). Potentiodynamic polarization, in-situ open-circuit potential, in-situ linear polarization resistance, and potentiostatic techniques were utilized in this investigation. The affected surface layers of the photoresist etched Cu were investigated using X-ray photoelectron spectroscopy (XPS) and scanning electron microscopy (SEM). The surface porosity was studied by atomic force microscopy (AFM). The addition of glycine at acidic pH slurries does not enhance the Cu CMP removal rate, yet the pH, the Cu removal rate was significantly increased. The surface porosity of Cu at basic pH is improved by the addition of 3-amino-1, 2, 4-trisulfo (ATA) inhibitor making only a little compromise in the removal rate. The Cu CMP mechanism with the addition of inhibitor and complexing agents at various pH will be discussed.

SESSION F7. CMP INTEGRATION
Chair: Fiona M. Doyle
Thursday Afternoon, April 30, 2003
Golden Gate B3 (Marriott)

1:30 PM E7.1 MECHANICAL MODELING OF DISHING IN COPPER CMP. C. Fred Higgs III, Inho Yoon, Sun Huan Ng, LipKong Yap, Steven Danglaj, Georgia Institute of Technology, Woodruff School of Mechanical Engineering, Atlanta, GA; Zhiquan Zhou, Georgia Institute of Technology, Microelectronics Research Center, Atlanta, GA.

Chemical mechanical polishing (CMP) is a manufacturing process used to remove and planarize metallic, dielectric, or barrier layers on silicon wafers. During polishing, a wafer is pressed against an elastic pad flooded with a chemically active slurry. CMP experiments revealed that a sub-surface pressure develops in the slurry during polishing. Dish results in CMP process when the wafer stress lines are removed at rates higher than those of the barrier and dielectric layers. This work discusses the importance of modeling dishing (and erosion) with considerations to the slurry fluid pressure.

2:00 PM E7.2 A NEW CLEANING TECHNIQUE FOR CORROSION PROTECTION IN ALUMINUM METALLIZATION. Masako Kodera*, Yohsikata Matsu,* Norito Miyashita, Masaharu Tasajimura,* and Shin-ichiro Uekusa*. Toshiba Corporation, Yokohama, JAPAN; *Elbara Corporation, Fujisawa, JAPAN; *Meiji University, Kawasaki, JAPAN.

A new cleaning technique using gas dissolved water has been found to be effective to protect corrosion in Al metallization, which is also useful in post-cleaning of Cu CMP as already reported. Corrosion is a significant concern in aluminum as well as in copper metallization. In Al CMP process, it often occurs in contact with DIW because of a big difference of surface potential between Al and a barrier metal in DIW. Gas dissolved water is able to change surface potential of various metal films and protect galvanic corrosion. For example, the difference of surface potential between Al and TiN is 700mV in DIW, which can be remarkably diminished in gas dissolved water. It has been confirmed that surface cleaning of Al CMP using gas dissolved water instead of DIW is successfully protective. Gas dissolved water is generated by injection of hydrogen and/or oxygen gas into DIW, or by electrolysis of DIW without additive. In the case of electrolysis of DIW, mode water generated at the modes of the

electrolytic cell has an ORP (oxidation reduction potential) of +4200 to +4100mV as Ag/AgCl and contains oxygen gas, while cathode water generates the cathodic ORP of -700mV to -710mV Ag/AgCl and contains hydrogen gas. Moreover both waters have a neutral pH so that they do not chemically attack a metal surface. It is expected that this technique is also effective in post-cleaning process of Al-Cu wiring formed by RIE. Because precipitation of copper at side walls of aluminum wiring often occurs during RIE and following process, Al is easily corroded during DIW rinsing step in wet cleaning, which often causes killer defects. The difference of surface potential between Al and Cu is 530mV DIW, while that is greatly decreased in gas dissolved water.

2:15 PM E7.3 DELAMINATION BEHAVIOR OF Cu-Low-k STACK UNDER DIFFERENT SLURRIES AND ABRASIVE DENSITIES IN SLURRY. A.K. Sidler, University of South Florida, Center for Microelectronics Research, Tampa, FL; Pasharur Zanye, University of South Florida, Department of Mechanical Engineering; P. Thakkar, University of South Florida, Department of Mechanical Engineering and Center for Microelectronics Research, Tampa, FL; S. Tangella, University of South Florida, Department of Industrial Engineering and Center for Microelectronics Research, Tampa, FL, and Ashok Kumar, University of South Florida, Department of Mechanical Engineering and Center for Microelectronics Research, Tampa, FL.

The dielectric constant of the interlayer dielectric films generates high capacitive across, which leads to increased signal propagation delay-time and cross-talk. A low dielectric constant material is required in order to improve the device performance. In the 50 nm node, International Semiconductors (ISI) projects a need for dielectrics with a bulk K value of <1.3 and effective K value <1.5 for the dielectric stack. Mechanical characterization of low dielectric constant (low-K) materials has shown that lower K typically also means lower elastic modulus and hardness. Due to lower mechanical strength, reduced cohesive strength and lack of compatibility with other interconnect materials, major challenges involve in chemical mechanical polishing (CMP) of these low-K materials. In this study we have investigated the polishing behavior of patterned copper samples with underneath different low-K materials using different slurries and slurry with wide range of concentrations of abrasives. CMP micro tribometer was used to polish the samples with different concentration of slurry (0.01-1.5 cm/s) and down-force (0.6-1 ps). Friction coefficient and wear behavior were also measured at different conditions. Atomic force microscopy and scanning electron microscopy were used to investigate the polished surface. As the abrasive density in the slurry increases, the delamination on the sample surface increases. Also different slurries have marked effects on the polishing of Cu. Attempt has been made to find the mechanisms of delamination due to the effect of abrasives.

3:00 PM E7.4 INTEGRATION CHALLENGES FOR CHEMICAL MECHANICAL POLISHING OF Cu/Low-k INTERCONNECTS. Jean-Marc Goudarzi, Jeffrey A. Lee, Thomas J. Absil, Intel Corporation, Santa Clara, CA.

The drive for improved performance of microelectronic devices has led to the prevalence of copper metallization and the aggravation of development of lower permittivity (low-K) dielectrics in BEOL interconnect structures. Progressive scaling of metal line widths coupled with the need to incorporate ultra low K (ULK) dielectrics, with K <2.7, presents numerous challenges for integration reliability. Chemical mechanical planarization (CMP) of Cu/Low K interconnect structures is particularly difficult owing to their reduced mechanical integrity. ULK dielectric materials are inherently weak and highly permeable, and are characterized by low Young's modulus and hardness, and relatively high coefficients of thermal expansion (CTEs). Copper interconnect structures incorporating ULK materials are more deformable, experience greater thermodynamic driving forces for delamination, and are more susceptible to chemical mechanical damage. During CMP of Cu/Low K interconnect structures, the relatively weak porous dielectrics are subjected to applied mechanical loading in an aqueous environment. Primary process concerns are delamination at critical interfaces, and Cu-over-polish reaction in pattern erosion and dielectric cap loss that can ultimately expose the porous dielectric to CMP slurry moisture and chemical attack. As minimum wiring dimensions decrease with successive technology nodes and progressively less dense interlayer dielectrics are required, planarization processes will become even more critical. Clearly, CMP tools and processes must be further developed to allow polishing of Cu in advanced Cu/Low-k systems. CMP process and conditions that are material specific must be designed for compatibility with porous low-K materials. In addition, new planarization techniques must be explored as viable alternatives to conventional technologies. The presentation paper will discuss the growth of integration costs, key reliability issues for chemical mechanical polishing of Cu/Low-K interconnects incorporating ultra low-K (porous) dielectric materials.
Integrated chip-scale prediction of copper
interconnect topology, Tae Park, Tamba Tugbawa, Hong Cui, Xiaolin Xie, and Don Neising, Microsystems Technology Laboratories, MIT, Cambridge, MA; Chadi Chaihanoorun, Chris Horst, and Greg Shans, Texas Instruments, Dallas, TX.

In copper integrated circuits, the performance of copper interconnect lines are directly related to the copper thickness loss that occurs due to the pattern dependent polishing characteristics in CMP. Polishing of the copper film is even more complicated by incoming thickness variation from electroplating which is also known to suffer from pattern dependencies causing non-uniform thicknesses across a die. Thus, all aspects of electroplated profile variation, its effect on CMP, and CMP pattern dependencies must be integrated to form a coherent procedure for the prediction of polished copper line thicknesses that is essential for process optimization as well as circuit performance and yield improvement. In this work, we present an integrated prediction of thickness variations in electroplating and CMP processes across an entire chip. We demonstrate the chip-scale prediction capability by first calibrating both electroplating and CMP models with experimental data using the same test mask. Then, using the calibrated plating model and the associated chip-scale simulation procedure, a prediction of plated copper topography variation is achieved for a random layout. Then, by integrating the electroplating model prediction result with the CMP model and chip-scale simulation procedure, the polished thickness variation is obtained for an entire die for the same random layout. Layout geometry extraction for each discretized region of a chip as well as layout parameter manipulation and model output integration are all critical elements, in addition to the model development itself, enabling the integrated chip-scale prediction of final copper interconnect thickness variation.