SYMPOSIUM F

Chemical-Mechanical Planarization

April 22 – 24, 2003

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* Invited paper

SESSION F1: CMP MODELING
Chair: Michael R. Oliver
Tuesday Morning, April 22, 2003
Golden Gate B3 (Marriott)

8:30 AM F1.1
THREE-DIMENSIONAL WAFER PROCESS MODEL FOR NANOTOPOGRAPHY. Takafumi Yoshida, YNT-jp.Com, Dept of TCAD, Hikari, JAPAN.

This paper proposes a three-dimensional wafer process model for nanotopography. This model allows us to predict the effect and behavior of nanotopography on the wafer processes especially for the wafer Mechanical/Chemical Lapping (MLP/CLP), wafer Single/Double Side Polishing (SSP/DSP) and device Chemical Mechanical Polishing (CMP).

8:45 AM F1.2
A MODEL OF CHEMICAL MECHANICAL POLISHING: THE ROLE OF INHIBITORS. Ed Paul, Stockton College, Pomona, NJ; Robert Vacassy, Cabot CMP, Aurora, IL.

An established model of CMP is extended to include the role of inhibitors. In CMP, a chemical reaction forms a surface film which is removed mechanically by abrasives. When inhibitor molecules bond to the surface film, the mechanical abrasion rate is reduced. The general model will be discussed, and then applied to W-CMP data explaining differences in the reduction of polishing rates for different inhibitors.

9:00 AM F1.3
RE-EXAMINING THE PHYSICAL BASIS OF PLANARIZATION LENGTH IN PATTERN DENSITY CMP MODELS. Xiaolin Xie, Tae Park, Brian Lee, Tamba Tugbawa, Hong Cai and Duane Boning, Microsystems Technology Laboratories, MIT, Cambridge, MA.

Chemical mechanical polishing (CMP) has become the enabling planarization method for copper CMP and shallow trench isolation (STI). CMP is able to reduce topography over longer lateral distances than earlier techniques; however, CMP still suffers from pattern dependencies that result in large variation in the post-polish profile across the chips. In the copper CMP process, the non-uniformity of copper thickness affects circuit performance and will cause integration and manufacturing problems. In the STI process, insufficient polish will leave residue nitride and cause device failure, while excess dishing and erosion degrade device performance. Predictive pattern dependent models of CMP processes are therefore highly desirable for use in optimization of a manufacturing flow, as well as for developing design rules, among other things. Our group has proposed several chip-scale CMP models, and all of them rely on the planarization length and pattern density model [1]. In the model, planarization length is the characteristics length of an elliptic weighting function based on the long-range pad deformation and pressure distribution during CMP. This semi-physical model is often adequate and usually gives a fitting error of a few hundred angstroms. As ever-shrinking device size pushes for tighter budget on post CMP uniformity, however, we need a chip-scale CMP model with better accuracy. In this work, we re-examine the physical basis for averaging weighting functions; particularly with the context of contact mechanics based model formulations. We also investigate different filter shapes, including square, cylinder, Gaussian and elliptical filters by comparing the results with experimental data. [1] D.O. Ouma, D.S. Boning, J.E. Chung, W.G. Easter, V. Saxena, S. Misra, and A. Crevasse, "Characterization and Modeling of Oxide Chemical Mechanical Polishing Using Planarization Length and Pattern Density Concepts," IEEE Transactions on Semiconductor Manufacturing, vol. 15, no. 2, pp. 232-244, May 2002.

9:15 AM F1.4
DETERMINING SLURRY UTILIZATION EFFICIENCY IN CMP PROCESSES USING MEAN RESIDENCE TIME TECHNIQUES. Ara Philipossian and Erin Mitchell, University of Arizona, Department of Chemical & Environmental Engineering, Tucson, AZ.

The overall goal of this study is to develop robust planarization processes resulting in significantly lower slurry consumption through fundamental understanding of the fluid dynamics of the process. In this work, the space bounded between the wafer and the pad is treated as a reaction chamber having its own slurry input and output streams. New techniques for measuring slurry mean residence time and volume of the wafer-pad region during polishing have been developed and analyzed as a function key processing parameters. Given the classical relationship between mean residence time, reactor volume and flow rate, the actual volumetric flow rate in the wafer-pad region can be determined experimentally and compared to the slurry flow rate introduced on the surface of the pad. The ratio of the two flow entities yields the slurry utilization efficiency for a given set of polishing conditions. Results indicate that depending on relative pad-wafer velocity, pad grooving, slurry flow rate and wafer pressure, slurry utilization efficiency can vary by as much as 2 orders of magnitude (0.2 to 20 percent). The largest contributor to utilization efficiency is determined to be the pattern of pad grooving due to its pronounced effect on volume of slurry entrained between the wafer and the pad. Increasing wafer pressure and slurry flow rate decrease utilization efficiency, while increasing the relative wafer-pad velocity causes slurry utilization efficiency to increase. These startling results attest to the wasteful nature of the CMP process and demonstrate the need for innovative polisher designs and pad grooving patterns. The above trends are explained using a simplified chemical engineering reactor model, which is then used to help identify optimum processing conditions for CMP.

9:30 AM F1.5
CHEMICAL RETENTION AND TRANSPORT STUDY IN A CONVENTIONAL COPPER CMP PROCESS. Udaya B. Patri, Sharath Hegde, Anurag Jindal and S.V. Babu, Department of Chemical Engineering, Center for Advanced Materials Processing, Clarkson University, Potsdam, NY.

Polishing pad is one of the prime components in a typical Chemical Mechanical Polishing (CMP) process. The structure and transport properties of a polishing pad are critical in determining the particle and chemical retention in a conventional CMP process. Our earlier paper investigated the particle retention and transport in two different polishing pads, IC-1400 and SUBA-500, during copper polishing. In this paper, the results of chemical retention and transport of IC-1400 and SUBA-500 pads during copper polishing are presented and discussed. The polish rate results from slurry-step-flow experiments with H2O2-glycine based slurries, where the concentrations of chemicals in the slurry are altered in steps during polishing, are correlated to the chemical retention and transport characteristics of these pads. The gradual decrease in the removal rate of copper with the stoppage of supply of H2O2 or glycine, after an initial 30 seconds of polish with a slurry containing both H2O2 and glycine, suggests that these chemicals are being constantly replaced during polishing. Further, the variation in the chemical retention capability of these two pads is shown to affect the polish rates of copper.

9:45 AM F1.6
IN-SITU TEMPERATURE MEASUREMENT DURING CHEMICAL-MECHANICAL PLANARIZATION OF GLASS AND OXIDE WAFERS. Jesse Cornely, Chris Rogers, Vincent P. Manno, Edward Chan, Tufts University, Department of Mechanical Engineering, Medford, MA; Ara Philipossian, University of Arizona, Department of Chemical & Environmental Engineering, Tucson, AZ; Sriram Anjur, Frank Kaufman, Cabot Microelectronics Corp., Aurora, IL; Mansour Moinpour, Ashwani Rawat, Intel Corp., Santa Clara, CA.

Knowledge of the temperature field beneath and near a wafer undergoing Chemical-Mechanical Planarization (CMP) is needed to understand the resultant material removal rate. In this research, a Dual Emission Laser Induced Fluorescence (DELIF) technique is used to optically measure the temperature directly beneath a translucent surrogate glass wafer during polishing. The DELIF system employs a UV light based, two camera imaging system similar to that used for in-situ slurry film thickness measurements. An infrared camera and a thermocouple are also used to develop a correlation between under-wafer and near-wafer thermal fields. Total friction forces are also measured. Most experiments are performed on a 1:2 scale laboratory tabletop rotary polisher with in-situ pad conditioning. A low abrasive concentration slurry was used to minimize wafer polishing during the course of an experiment. A confirmatory experiment was also run on a SpeeedFam-IPEC 472 polisher. Ungrooved, dyed Freudenberg FX-9 polishing pads were used in all tests. The effects of wafer curvature, down force, and linear velocity on temperature during CMP are studied. The bow wave temperatures near concave wafers are 3°C to 5°C higher than the corresponding values for convex wafers. Similarly, temperatures under concave wafers are 5°C to 6°C higher than those beneath convex wafers (uncertainty of 0.5°C). The friction force per unit area is typically 2 kPa to 3 kPa higher for concave wafers. Under-wafer temperatures as high as 35°C were measured for concave wafers at higher applied wafer pressures (41.4 kPa) or linear velocities (0.93 m/sec). Bow wave temperatures reach as high as 32°C at a linear velocity of 0.93 m/sec. Linear velocity has little effect on the temperature under convex wafers. Increasing slurry abrasive concentration causes an increase in temperature, despite a decrease in the coefficient of friction. A correlation across the entire data set, with an $R^2 < 0.96$, exists between the bow wave temperature and the temperature beneath the wafer. SiO_2 wafers exhibit behavior similar to glass wafers when polished under the same conditions. The DELIF temperature measurement technique was scaled to an industrial scale polisher and a small set of data was acquired. These data show that the lab scale polisher accurately represents the industrial scale polisher processes. The paper will conclude with preliminary YAG-laser based DELIF data which provide greater spatial and temporal resolution of temperature and film thickness measurements.

10:30 AM *F1.7
NEWS FROM THE 'M' IN CMP – VISCOSITY OF CMP SLURRIES, A CONSTANT? Wolfgang Lortz, Frank Menzel, Degussa AG, R&D Dept., Aerosil & Silanes, Hanau, GERMANY; Ralph Brandes, Frederick C. Klaessig, Thomas Knothe, Degussa Corporation, Piscataway, NJ and Parsippany, NJ; Takeyoshi Shibasaki, Nippon Aerosil Co., Ltd., Tokyo, JAPAN.

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 non-Newtonian or even dilatant effects. While for most calculations in the literature the viscosity is regarded as a constant, the 'real' viscosity of a CMP-slurry can vary widely at high shear rates. Typically viscosity measurements are carried out with systems based on a rotating cylinder or a plate. A plate system 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 m/sec and a distance between the wafer and the pad of 20 μm. If parts of the polishing pad come closer to the wafer or especially if they come close to the edge of structures on the wafer (for example 1 μm instead of 20μm) then the shear rate will significantly increase in theses regions to values as high as 1,000,000 1/sec. When the shear rate is very high, the viscosity depends mostly 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 fumed 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. The dependence of high shear rate viscosity of different silica slurries on BET-surface area, concentration and preparation methods will be shown and the impact on the CMP process will be discussed.

11:00 AM F1.8
ATOMISTIC MECHANISMS UNDERLYING CHEMICAL MECHANICAL PLANARIZATION OF COPPER. Y.Y. Ye, R. Biswas, Iowa State University, Dept of Physics, Ames Lab & Microelectronics Center; A. Bastawros, Iowa State U, Dept. of Aerospace Engg.; A. Chandra, Iowa State University, Dept. of Mechanical Engg.

To understand the fundamental atomistic scale mechanisms underlying CMP of copper we have performed molecular dynamics of copper surfaces using the embedded atom method. We have simulated two basic processes of surface planarization consisting of mechanical abrasion and chemical dissolution. Mechanical abrasion produces rough planarized surfaces with a large chip (debris) in front of the abrasive particle. The addition of chemical dissolution is critical for achieving very smooth planarized copper surfaces, and leads to considerably smaller frictional forces that prevent bulk dislocations. The material removal rate will be simulated as a function of the strength of the chemical dissolution. We will also study the temperature gradients occurring during the processing conditions, identifying regimes of polishing. Simulation results will be related to experiment.

11:15 AM F1.9
WAVELET BASED MULTIRESOLUTION MONITORING OF A NANOMACHINING PROCESS IN SEMICONDUCTOR MANUFACTURING. Rajesh Ganesan and Tapas K. Das, Department of Industrial and Management System Engineering, University of South Florida Tampa, FL; Ashok Kumar and Arun K. Sikder, Nanomaterials and Nanomanufacturing 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), researchers are looking for new and improved methods to meet 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 bands of the time domain sensor data, and 4) the ability 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 multiscale analysis approaches have 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 multiscale 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 multiresolution 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-k dielectric layers by analyzing nonstationary acoustic emission (AE) signal and coefficient of friction (CoF) signal collected during copper damascene (Cu-low k) 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 F1.10
DYNAMIC CONTACT CHARACTERISTICS FOR CMP MODELING. Wonseop Choi, Seung-Mahn 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 (platen velocity and down pressure) and particle characteristics (particle size and particle concentration). These variables also affect material removal rate during CMP. In this talk, 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 F1.11
SPECTRAL ANALYSIS OF FRICTIONAL FORCES IN CMP. Ara Philipossian, Leslie Charns and Daniel Rosales-Yeomans, University of Arizona, Department of Chemical & Environmental Engineering, Tucson, AZ; Chris Rogers, Tufts University, Department of Mechanical Engineering, Medford, MA; Toshiroh Doy, Saitama University, Department of Mechanical Engineering, Saitama, JAPAN; Masaharu Kinoshita, Rodel-Nitta Company, Tokyo, JAPAN.

Spectral analysis of real-time frictional data obtained during ILD 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 IC-1000 pad groove shapes (un-grooved, perforated, XY-groove and K-groove) and PL-4217 fumed silica concentrations (2.5 to 25 percent silica by weight). Across a wide range of wafer pressures (2 to 6 PSI) and wafer-pad velocities (0.31 to 0.93 meters per second) studied, results indicate that, for a given pad, increasing abrasive concentration from 2.5 to about 6 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 9 to 25 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 polish 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 Stribeck Curves.

SESSION F2: CMP SCIENCE
Chair: Duane S. Boning
Tuesday Afternoon, April 22, 2003
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 agents and mechanical stress applied between a model single asperity and a solid surface. We show the consequences of combining highly localized mechanical stress (due to contact with an atomic force microscope–AFM tip) 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. We also present results on tip induced recrystallization (at small normal forces) and unique patterning produced by scanning in super-saturated 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 SIMULATION OF INTERACTION FORCES IN CMP APPLICATIONS. Ivan U. Vakarelski, G. Bahar Basim, Scott C. Brown, Yakov I. Rabinovich, Brij M. Moudgil, Department of Materials Science and Engineering 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 forces measurements were performed between a silica particle and a silica wafer at the presence of surfactant dispersants and at pressures close those exhibited in the CMP. In our previous study it was shown that the surfactant dispersants were effective at stabilizing the slurries but yielded minimal material removal. The lateral force measurements reviled that the low removal 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 as 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. Hoyoung Kim, Dong-Woon Park, Chang-Ki Hong, Woo-Sung Han, Joo-Tae Moon, Semiconductor R&D Center, Samsung Electronics Co. Ltd., Yongin, KOREA.

This study presents the effect of pad properties, such as elastic modulus and surface roughness, on the planarity in a CMP process. A systematic method to measure *planarization length*, which represents the die–scale planarity in a quantitative 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 dishing amount, which represents feature–scale planarity, 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. Ashraf Bastawros, Iowa State University, Dept of Aerospace Engineering and Engineering Mechanics, Ames, IA; Abhijit Chandra, Sunil Doddabasanagouda, 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 predicted 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 SOAK 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 Moinpour, Intel Corporation, Fab Materials Operation, Santa Clara, MA.

During a traditional CMP process, which involves application of polishing pads and slurry, the pad properties can be substantially and irreversibly changed as the result of slurry/rinse water absorption. The polyurethane-based "hard" and "soft" pads were exposed at room temperature to DI water and slurries for different time durations. Additionally, to simulate the effect of slurry pH on the slurry absorption and pad properties, some pad samples were exposed to various pH buffer solutions. The adsorption was monitored using measurements of the weight changes of the exposed specimens before and after immersion. Substantial difference in diffusion behavior of the "soft" and "hard" pads was 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), Dynamical Mechanical Analysis (DMA), Modulated Differential Scanning Calorimetry (MDSC), Thermal Gravimetric Analysis (TGA). Thermal and mechanical properties of the pads were affected by soak in slurry and water. The most interesting findings are listed below: TMA results for soft pads indicated considerable shrinkage of the pads after soak for four weeks in slurry 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 20°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 Mongne, 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 there are transferring elements onto copper and urethane surfaces due to friction. In this presentation, we discuss a new polishing mechanism.

4:00 PM F2.8
EFFECT OF COEFFICIENT OF FRICTION AND PROCESS TRIBOLOGY ON ILD REMOVAL RATE FOR VARIOUS PADS AND SLURRY ABRASIVE CONCENTRATIONS. Ara Philipossian and 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 pad-slurry-wafer region dramatically affects 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 groove types, and six slurries with varying abrasive concentrations are used to polish ILD films over a wide range of wafer-pad velocities and pressures. A new parameter termed the "tribological mechanism indicator" is defined and extracted from the resulting Stribeck curves. The information on COF, "tribological mechanism indicator" and ILD removal rate results in a series of "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 (the latter 2 are incorporated in the Sommerfeld Number argument) can dramatically shift the tribology of the system from "boundary lubrication" to "partial lubrication". Removal rate studies indicate a direct correlation between COF and Preston's constant for abrasive concentrations in excess of six weight percent. At lower abrasive concentrations (six percent or lower), removal rate is shown to depend on the contact area between the pad and the wafer rather than on COF. This finding sheds new light on the effect of abrasive concentration on removal rate since depending on their impact on COF, higher abrasive concentrations may not necessarily result in higher removal rates. The study concludes by presenting different scenarios which demonstrate the need to match slurry abrasive concentration to particular pad surface properties for optimum removal rate.

4:15 PM F2.9
TRANSIENT ELECTROCHEMICAL MEASUREMENTS DURING COPPER CHEMICAL MECHANICAL POLISHING.
Seung-Mahn Lee, Su-Ho Jung, Wonseop Choi and Rajiv K. Singh, Department of Materials Science and Engineering and Engineering Research Center for Particle Science and Technology, University of Florida, Gainesville, FL.

The planarity, defectivity and the polish rate in a CMP process are dependent of the nano-scale chemical and mechanical interactions involving the formation and the removal of a chemically modified surface layer. The objective of this talk is to provide an understanding of the dynamics of the chemically modified surface layer formation during copper CMP. We have performed in-situ and ex-situ transient electrochemical measurements during copper CMP. The results showed that the formation kinetics and thickness of the chemically modified surface layer are strongly dependent on the slurry chemicals, such as an oxidizer, a corrosion inhibitor and a complexing agent, and their concentrations. Polishing rate was also well correlated to the results of the electrochemistry. Characterization measurements (XPS and TEM) were conducted to confirm and validate the electrochemical results. The talk will also address the physical properties, such as hardness and Young's modulus, of the chemically modified surface layer conducted by the nanoindentation.

4:30 PM F2.10
EVALUATION OF MECHANICAL AND TRIBOLOGICAL PROPERTIES OF ULTRA-LOW k DIELECTRIC MATERIALS FOR THEIR INTEGRATION IN Cu DAMASCENE STRUCTURES.
Parshuram Zantye, University of South Florida, Department of Mechanical Engineering and Center for Microelectronics Research, Tampa, FL; Arun K. Sikder, University of South Florida, 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 constant push towards sub-micron miniaturization of device dimensions, increased density of devices, and faster processing power has led to the development of new interconnect technologies that use Copper and ultra low-K ($K<2.2$) polymer based dielectrics. The incorporation of Copper as a replacement for previously used conducting interconnect material, Aluminum (and Aluminum alloys), has further reduced the resistance of the metal interconnects and improved the performance of the ICs. Due to the reduced feature sizes, the surface planarity of the deposited thin films is critical in device fabrication. As controlled etching of Cu to form the interconnect pattern is a not a worthwhile task, CMP has emerged as the method of choice for global planarization of dielectric and metal films. The Ultra low-K Interlayer dielectrics (ILD) thin films have markedly lower mechanical properties (hardness and Youngs modulus) as compared to standard ILD materials like TEOS, mostly due to their porous nature. Thus, examination of the mechanical and tribological properties of Cu and the various ultra low-k ILD thin films and the study of the various defects that occur during their CMP are of paramount importance of the implementation of these films in Cu damascene interconnect structures of a microelectronic device.

4:45 PM F2.11
A NOVEL PROCESS ON FIXED ABRASIVE PADS FOR THE MANUFACTURING OF HIGHLY PLANAR THICK FILM SOI SUBSTRATES. Martin Kulawski, Kimmo Henttinen, Ilkka Suni, VTT Microelectronics, Espoo, FINLAND; Frauke Weimar, 3M Laboratories (Europe), Neuss, GERMANY; Jari Makinen, Okmetic Oy, Espoo, FINLAND.

The manufacturing of thick film silicon-on-insulator (SOI) substrates requires a significant amount of mechanical treatment. In thin film SOI production the Smartcut process leaves an already highly uniform surface, which only requires a small amount of polishing. Processing of thick film SOI however requires extensive grinding and polishing to remove most of the bonded device wafer. Therefore, care has to be taken for the non-uniformity of the thinning processes. While grinding leads to an overall flatness within 0,5 μm across the wafer it leaves a sub-surface damage of up to 6 μm deep in the substrate, which has to be removed by subsequent chemical mechanical polishing (CMP). The conventional slurry based processing however often leads to strong thickness non-uniformity. Thus the processing area on the ready SOI substrate is decreased. A new approach using Fixed Abrasive pads has been undertaken to overcome this problem. The theoretical models indicating the advantages of the 2-body system of the Fixed Abrasive configuration vs. the conventional 3-body system of slurry based polishing have been convincingly demonstrated in practise upon experiments in a wide range of parameters. As a result it is possible to maintain or improve the flatness of wafers after backgrinding while, simultaneously removing the sub-surface damage. A surface quality of prime wafers can be reached on the device layer. Capacitive thickness measurement scans and atomic force microscopy (AFM) monitoring confirm the results. A detailed comparison with conventional processing has been carried out to clarify the advantages on bulk silicon wafers. Decoration etching is used to analyse the wafer surface quality in terms of oxide induced stacking faults (OISF). The new process recipe has been transferred to SOI substrates to corroborate the benefits of Fixed Abrasives. As a result a possible alternative processing method is proposed for manufacturing thick film SOI substrates with improved uniformity.

SESSION F3: CMP SLURRIES, PARTICLES

Chair: Suryadevara V. Babu
Wednesday Morning, April 23, 2003
Golden Gate B3 (Marriott)

8:30 AM *F3.1
Ta/LOW-k CMP WITH COLLOIDAL SILICA PARTICLES.
Patrice Beaud, Didier Bouvet, Pierre Fazan, Swiss Federal Institute of Technology, Electronics Laboratory, Lausanne, SWITZERLAND; Eric Jacquinot, Life Science & Electronic Chemicals Division, Clariant (France), Trosly Breuil, FRANCE; Hiroyuki Aoki, Tomoko Aoki, Polysilazane Business Group, Life Science and Electronic Chemicals Division, Clariant, JAPAN.

Low-k/Cu interconnect integration achievement is one of the key issues for the future sub-100 nm technologies. Nowadays, no definitive integration scheme has been reported. Low-k integration is especially difficult because the trench/via etch and CMP processes can damage its properties. In the present work, we present results on different materials that could be used in such integration. We focused our study on the barrier (Ta/TaN) and cap/stop (silicon nitride) layers on a non-porous low-k material, that is, a spin-on-dielectric (SOD) of the methylsilsesquioxane (MSQ). CMP was done with mono-dispersed colloidal silica slurries. In a first approach, the slurries compositions mainly differed by their pH and abrasive characteristics. Particle size ranged from 7 to 80 nm, with pH varying from 2 to 11. The sensitivity of Ta/TaN and low-k removal rates will also be reported. With Ta/Si_3N_4 selectivity of 3:1 and Si_3N_4/low-k selectivity ranging from 3:1 to 10:1, nitride is not a efficient stop layer for colloidal silica slurries. Then additional chemicals were tested in order to modify the different selectivities. Scanning electron microscopy (SEM) and atomic force microscopy (AFM) of the different films were carried out in order to evaluate the impact of CMP on their surface quality. Measurements didn't show any surface degradation or/and scratches, and no delamination has been observed. We attempted to highlight possible damages on the low-k by optical measurements correlated by thickness measurements and k value measurement. We also investigate extendibility of this technology to porous ultra low-k materials.

9:00 AM F3.2
EFFECT OF CERIA PARTICLE SIZE DISTRIBUTION AND PRESSURE INTERACTIONS IN CHEMO-MECHANICAL POLISHING (CMP) OF DIELECTRIC MATERIALS.
Naga Chandrasekaran, Ted Taylor, Gundu Sabde, Micron Technology, Inc., Boise, ID.

Abrasive particle type and its size distribution are primary factors affecting the polish rate and surface generation in chemo-mechanical polishing (CMP). Initial pioneering work on the effect of particle size distribution has exhibited contradicting data suggesting an increase, decrease, and independence of polish rate and roughness with particle size. Also, in general, the particle size is considered to be primarily the mean particle size. However, it should be noted that both the mean and the tail particle size distributions are of significant importance and should be treated separately. In this investigation, the effect of ceria particle size distribution and pressure interactions on dielectric (oxide and nitride) surface generation in CMP is studied in detail. Six different slurries were tested and they are defined by their D50 and D99 (particle size at 50% and 90% solids, respectively). For given slurry, both the oxide and nitride removal rate were observed to increase with pressure. With decreasing D50, the pressure dependence on removal rate was observed to change from linear to logarithmic indicating an early saturation. It was also observed that the D50 affects the removal rate significantly and its pressure dependence while the D99 affects the surface roughness and the degree of micro-scratches. Slurries with similar D50 and varying D99 showed insignificant rate differential. However, addition of a selective component that provides selectivity between oxide and nitride to the slurry 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 slurry. A term defined as Particle Count Identifier (PCI) is introduced here that provides a comparative gage to evaluate the number of particles in tail and mean and hence define the distribution more accurately.

9:15 AM F3.3
INTERACTION BETWEEN CERIA AND HYDROXYLAMINE.
Subramanian Tamilmani, Wayne Huang and Srini Raghavan, Department of Materials Science and Engineering, University of Arizona, Tucson, AZ; Robert Small 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 dissolution of ceria has been determined by ICPMS. Removal of ceria particles from oxide surfaces using hydroxylamine-based chemistries 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 perseveres in the integration schemes to <0.065 nm on manufacturers roadmaps. As devices scale smaller, the key metric that is specifically tied to the slurry is defectivity. The roadmap addresses defect type, threshold size and concentration. The call to arms for slurry R&D groups intent on developing the next generation ILD slurries is "reduce microscratches." 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 to 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 microscratches, to show how advanced processing can ultimately lead to an improved ILD slurry. We will break down potential mechanism of microscratch formation and identify, based on experimental evidence, the potential root causes. We will then tie improvements in our ILD slurry to these root causes, making the case that there will be a reduced number of microscratch "events" with this new slurry during polishing. We will conclude with a description of our defect review methodology and a presentation tying the effects of the specific attributes of an improved ILD slurry to defect type and characteristics.

10:15 AM F3.5
THE STUDY OF PARTICLE ADHESION FOR CHEMICAL MECHANICAL POLISHING USING PACKED COLUMN TECHNIQUE. Zhenyu Lu, Egon Matijevic and S.V. Babu, Departments 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 dispersions of uniform particles, 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. However, 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 NANOPOROUS SILICA PARTICLES FOR LOW DEFECTIVITY IN LOW-k 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 of CMP slurries typically employs hard abrasives such as alumina or silica 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 slurry design is require. We have studied the nanoporous 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 suitably modified. Using these particles in the CMP slurries, we can reduce defectivity in low-k dielectric polishing. For this work, the spherical nanoporous silica particles with controlled particle size and surface porosity have been prepared by a precipitation technique. The interaction between the slurry particle and wafer substrate has been investigated by direct force measurement of AFM. We also have inspected the surface defects of wafers polished in nanoporous silica particle based slurry systems under AFM and SEM.

10:45 AM F3.7
NANOSCALE AND MICROSCALE MODELING OF CHEMICAL MECHANICAL POLISHING IN METALS AND DIELECTRIC SYSTEM. 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. A 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 appproach. The theoretical results will be compared with the epperiments conducted on silica and metal (copper and tungtsten) 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 Morning, April 23, 2003
11:00 AM
Golden Gate B3 (Marriott)

F4.1
MODELING OF CMP ON A LOCALIZED SCALE.
Shelley R. Gilliss, 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 minimal 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, sub-surface damage and slurry chemistry must all be tractable and controllable. Often when polishing on larger scale machines (12 inch platens 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 cm^2 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 slurry 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 spectroscopy; and specimens can be ready for characterization by transmission-electron microscopy by polishing 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.

F4.2
CeO2 SLURRY FOR CHEMICAL MECHANICAL PLANARIZATION. Xiangdong Feng, Robert Y.-S. Her, Wei Zhang, and Jackie Davis, Ferro Corporation, Independence, OH.

Chemical-mechanical polishing (CMP) slurries are used, for example, to planarize surfaces during the fabrication of semiconductor chips. CMP slurries typically include chemical etching 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 used in a CMP slurry can have a profound effect on the polishing rate. Over the years, CMP slurries have been formulated using abrasive particles formed of, for example, alumina (Al2O3), ceric oxide (CeO2), iron oxide (Fe2O3), silica (SiO2), silicon carbide (SiC), silicon nitride (Si3N4), tin oxide (SnO2), titania (TiO2), titanium carbide (TiC), tungstic oxide (WO3), 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 nano-sized Cerium Oxides and its composite particles in the size range of 5 to 100nm for use CMP applications. It involves first the formation of a uniform clear solution containing cerium and its composite elements. This uniform solution is then made into a gel-like material through introduction of bases such as amonium water. These gel-like materials were then breakdown 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.

F4.3
ANALYSIS OF CERIA ABRASIVES BY EELS IN AN FETEM. Shelley R. Gilliss, 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: CeO_2) is one of the most widely used abrasives for the planarization of silicate glasses. Extensive work has been done on the characterization of ceria abrasives. Inductively coupled plasma chemical analysis, surface-area analysis, and zeta-potential characterization are 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 related understanding of the composition. Ceria abrasives have been investigated using electron energy-loss spectroscopy (EELS) in a field-emission gun transmission electron microscope (Philips CM200FEG). By using a technique such as EELS in a TEM 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 La or just Ce 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.

F4.4
Transferred to F5.8

SESSION F5: CMP TOPICS, INCLUDING NOVEL DEVICES

Chair: Katia Devriendt
Wednesday Afternoon, April 23, 2003
Golden Gate B3 (Marriott)

1:30 PM F5.1
SLURRY ADMITTANCE AND ITS EFFECT ON POLISHING. David R. Evans, SHARP Laboratories of America, Inc., Camas, WA.

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 and, therefore, 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 at will. 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 but 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, pad wear and texture, etc. 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. Observed patterns of material removal on substrates polished with a fixed orientation are correlated and discussed.

1:45 PM F5.2
DETERMINING THE EXTENT AND IMPACT OF FLUID DYNAMICS TRANSIENTS AND NON-IDEALITIES DURING 30-SECOND PLANARIZATION PROCESSES. Ara Philipossian, Erin Mitchell, University of Arizona, Department of Chemical & Environmental Engineering, Tucson, AZ.

Understanding the extent of process transients and flow non-idealities 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 non-idealities. 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 polish 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-CSTR. This information is shown to be critical in ensuring uniform fluid distribution in the wafer-pad region. Additionally, a novel method is developed to demonstrate the effectiveness of a new dimensionless parameter, the 'Turnover Ratio', which represents the ratio of mean residence time (a fluid dynamics indicator) to polish time (a process and ITRS 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 then reviewed which demonstrate the utility of selecting 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, Matt Vanhaneham, 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 "kinder 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 to achieve the performance requirement. 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 reduce dishing and recess. Because 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/ULK CMP, we considered both mechanical and chemical aspects: gentle polish and tunable 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 F5.4
COPPER CMP USING ABRASIVE FREE POLISH ON ORBITAL AND ROTATIONAL PLATFORMS. Thomas Laursen, Ismael Emesh, Ben Palmer, Brian Mueller, Saket Chadda, SpeedFam-IPEC, Chandler, AZ.

Abrasive free polish (AFP) has gained acceptance as an alternative to polishes 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 polishers in which case the polish rate versus pressure relationship is near-Prestonian. However, the slope of this linear relationship is less than usual resulting in significant rates at lower pressures. These relative high rates at low pressures provide a process window for developing low-pressure CMP processes, which are required for polishing wafers containing low-k dielectrics. In contrast to this polish behavior on orbital tools, substantial polish rates on rotational tools were initially only observed using pressures at or above 3 psi. This paper covers polishing studies using the abrasive free polish on both rotary and orbital tools and shows that both platforms in reality obey the same Prestonian relationship. This result provides the basis for proposing a mechanism that explains the apparent difference in Prestonian behavior.

2:30 PM F5.5
LOW STRESS CHEMICAL MECHANICAL POLISHING OF COPPER/LOW k BASED INTERCONNECTS. Rajiv Singh, Seung-Mahn Lee, and Su-Ho Jung, University of Florida, Department of Materials Science and Engineering, Gainesville FL; Deepika Singh, Sinmat 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 may 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 effects, aging characteristics of the particles 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 schemes have been developed which decreases the size of the processing window for optimum 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 defectivity, planarity and ease of slurry handling and use also are significantly enhanced. By using specific chemistries 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 F5.6
INTERPLAY BETWEEN pH, OXIDIZERS, CORROSION INHIBITORS AND CHELATING AGENTS ON THE CHEMICAL MECHANICAL POLISH BEHAVIOR OF COBALT AND IRON. Jay Jayashankar, 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 semiconductor 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 fabrication of the read and write head structures. The development of CMP slurry chemistries for the above magnetic materials that provide good removal rates, planarity, polish uniformity, excellent surface finish and tailored selectivity is key to enabling 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 chemistry factors such as abrasives, pH, oxidizer concentration and chelating agent concentration, corrosion inhibitors and polish velocity on the polishing characteristics of Cobalt and Iron. For this purpose, detailed potentiodynamic measurements were conducted under dynamic (polish) and static (stationary) conditions. The results of these measurements are correlated with weight loss studies, as well as the predictions from Pourbaix diagrams.

3:30 PM F5.7
CMP REVISITED FOR THE MEMS / FOUNDRY ERA. Lawrence Camilletti, 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 their typical usage. IR arrays atop half-micron analog process resurrections, integrated and add-on stacked MIMs, post fab thick Cu inductors atop 6 um terminal metal, reference plane implementation and general MEMS friendly processing has required a ‘regression’ from the more glamorous abrasive free, low-k, in-laid 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, thru-put) assumptions. Sacrificial removal budgets as a function of topography, pattern density, and feature size distributions are seen to change planarization distance assumptions in the light of dummification blocking layers, ultra thick film conformality / defectivity characteristics, as well as minimum and maximum DRCs used to circumvent previous non-CMPed processing. Characterization of the high speed and pressure removal processing evaluated confirms the cross-over transition between decreases in intra-die with increases in inter-level variations, providing insight into deposition thickness optimizations as well as targeting constraints when +8um of dielectric require CMP. Metrology requirements have likewise proven non-trivial, with interference / information overload from thick films needing balanced with aggressive spot size requirements; each affected differently by large grain structure and novel material dispersion characteristics. In this work we present the results of the characterization efforts noted above as well as considerations that balance customer and production requirements. Incremental high-speed and high-pressure processing results will quantify intra-die and WIWNU impacts via ANOVA using several different topographical and pattern d! ensity challenges / scenarios.

3:45 PM F5.8
TRIBOLOGICAL CHARACTERIZATION OF POST-CMP BRUSH SCRUBBING. Ara Philipossian and Lateef Mustapha, University of Arizona, Department of Chemical and Environmental Engineering, Tucson, AZ.

Brush scrubbing 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 novel PVA brush scrubber capable of brush rotation and oscillation 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 Sommerfeld Number, indicate that applied brush pressure has a pronounced effect on process tribology and the magnitude of COF. At high to moderate pressures, the tribological mechanism is that of “mixed lubrication” where 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 1.5 to 10.7, the tribological mechanism shifts to “hydrodynamic 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 to 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 important 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. The 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 transform analysis of the frictional force signal resulting from various operating conditions is shown to be a valuable tool in understanding and interpreting the experimental data.

4:00 PM F5.9
PLANARISATION OF PATTERNED ALUMINIUM/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 recessed into the diamond substrates to create a near planar surface. This allows the deposition of higher quality oriented ZnO [1]. However the recessed Al electrodes required here are significantly more difficult to fabricate than the higher aspect ratios (~1 to 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 larger lateral dimensions are encountered. Thus a twofold challenge exists - (a) 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 (1cmx1cm) 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 ~80nm. (For 1μm widths, the diamond trench aspect ratio is 0.08). Aluminium (120nm thick) was sputter deposited on to the etched diamond and was polished using either (i) a solution of 0.05μm silica on a neoprene polishing cloth (Struers SP-PoliCel1) or (ii) using a ~0.12mm thick Teflon pad with colloidal solutions of 0.05μm or 0.02μm silica. Using AFM scans and optical microscopy 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 removal and superior uniformity in the electrode patterns. There was only marginal improvement when using 0.02μm silica instead of 0.05μm. 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 of c-axis ZnO on a lithographically patterned metal/diamond substrate," Proc. Spring MRS vol. 672, pp.O8.21.1-6. April 2001.

4:15 PM F5.10
THE DEVELOPMENT OF A DIRECT-POLISH PROCESS FOR STI CMP. Antonella Martin, Guilia Spinolo, Sonia Morin, Maurizio Bacchetta, Francesca Frigerio; ST Microelectronics, Agrate, ITALY; Maurizio Tremolada, Applied Materials Europe, Agrate, ITALY; Benjamin A. Bonner and Peter McKeever, Applied Materials, Santa Clara, CA.

Chemical mechanical planarization (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. Termed 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 0.13mm technology node. Two different direct polish processes were developed, both using high-selectivity slurry (HSS). The final and initial direct polish processes show an overall cost reduction of 77.5% and 58% compared to reverse mask, respectively. The final process is currently in production ramp up. One 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 resulted in a range of 4.2nm range, while the reverse mask resulted in a 19.0nm range across the 200mm wafer. Direct polish processes on multiple polishers using industry standard silica slurries have post-CMP silicon nitride ranges of 14.0 to 16.0nm. 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 planarity achieved after direct polish.

SESSION F6: COPPER AND BARRIER SLURRIES
Chair: David J. Stein
Thursday Morning, April 24, 2003
Golden Gate B3 (Marriott)

8:30 AM *F6.1
SUPRAMOLECULAR ABRASIVE-FREE SYSTEM FOR Cu/SILK CMP. Jason Keleher, Kenneth Rushing, Yuzhuo 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 planarization efficiency. More specifically, the polished surface should be free of defects such as scratches, pits, corrosion spots, trench copper loss, and residue particles. For copper/low k 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 anticipated and realized that defects such as severe scratching, particle contamination and slurry instability via particle aggregation or settling will be significantly reduced. In addition, with proper formulation, an abrasive free process can also 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 containing system such as step height reduction efficiency can be realized without the side effects often introduced from solid particles. In this presentation, some designing 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 blanket and patterned wafers will be discussed.

9:00 AM F6.2
ELECTROCHEMICAL MEASUREMENTS DEMONSTRATE PERFORMANCE OF BTAH AND ALTERNATE PASSIVATING AGENTS ON COPPER IN A HYDROXYLAMINE 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 an aggressive passivating agent but leaves residues that scratch the copper surface and impede inter-metallic 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. Cho et al[1] have shown the primary Cu-BTA layer lies flat on the copper surface while subsequent layers stand on edge. Metikos-Hukovic et al[2] demonstrated formation of the Cu(I)-BTA compound on copper surfaces. Other workers 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[3], and slower formation of secondary layers of a bi-layer passivation.
Electrochemical data is reported for organic passivating (chelation/adsorbtion) agents BTAH (see insert), ammonium salicylate, maleic acid, malonic acid and 3-methyl-2-oxazolidinone during abrasive free CMP (chemical mechanical planarization) of copper coated silicon wafers as possible replacements for BTAH. Measurements conducted in 1.52M hydroxylamine sulfate at pH 3.5, 5.5 and 7.5 produced potential steps as well as passivation removal 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.

1. Cho, Park, Kuk and Sakurai, Corrosion, National Association of Corrosion Engineers Annual Conference, May 14, 245, 1998, 1-11.
2. Metikos-Hukovic, Furic, Babic and Marinovic, *Surf. Interface Anal.* 27, 1999, 1016-1025.
3. Ein-Eli, Rabinovich, Rabkin and Starovetsky, Electrochemical Society Conference, Salt Lake City, October 20-24, 2002.

9:15 AM F6.3
SELECTIVITY STUDIES ON TANTALUM BARRIER LAYER IN COPPER CMP. Arun Vijayakumar, Tianbao Du, Kalpathy Sundaram, Vimal Desai, 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 planarization (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 result 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 needed to obtain good planarity. The aim of this work is to obtain a better understanding on the slurry selectivity for copper and tantalum and to develop slurries with best selectivity performance. In this work, the effect of several chemical parameters (abrasive type, oxidizer type, concentration, pH etc.) was studied through static and dynamic tests using advanced electrochemical techniques and surface analysis techniques. Polishing experiments are carried out on metal disks and blanket films on wafers. The surface layers of the statically etched copper and tantalum discs were investigated using X-ray photoelectron spectroscopy (XPS) and the surface defects such as scratches and dishing effects are studied using thin film surface analytical tools. Polishing rate results show that alumina-based slurry polished copper very well whereas tantalum removal was very low. However, for the silica-based slurry the tantalum shows much higher removal rate than copper and it was also observed that silica produced lesser scratches and much better surface planarity. XPS results indicate that a strong interaction between silica and tantalum may cause the higher CMP removal rate.

9:30 AM F6.4
ELECTROCHEMICAL STUDY OF COPPER CMP MECHANISM: THE EFFECT OF OXIDIZER CONCENTRATION IN COPPER CMP. Jin Lu and S.V. Babu, Clarkson Univ., Dept of Chemical Engineering, Potsdam, NY; John Garland, Christopher Pettit, Dipankar Roy, Clarkson Univ., Dept of Physics, Potsdam, NY.

The process of copper chemical-mechanical planarization (CMP) can be considered as an erosion corrosion process. Such a process can be efficiently studied by in situ and ex situ electrochemical techniques, such as potentiodynamic scan, open circuit potential (OCP) monitoring and electrochemical impedance spectroscopy (EIS), etc. Using a copper disk as the working electrode in an electrochemical cell, slurries with different oxidizer concentrations have been investigated with the aforementioned techniques. Corresponding dissolution tests and polishing experiments were also studied and compared. It is shown that changing the oxidizer concentration leads to the formation of surface films with different structure and composition on the copper surface during CMP process. The nature of these films controls the rate of copper corrosion. These results could be used to explain the change of copper removal rate in different oxidizer concentration, as well as to understand the dynamic process of copper CMP.

10:15 AM *F6.5
MECHANISMS OF PASSIVATION OF COPPER IN CMP SLURRIES CONTAINING PEROXIDE AND COMPLEXING AGENTS. Ling Wang, Amnuaysak Chianpairot, and Fiona M. Doyle, University of California at Berkeley, Department of Materials Science and Engineering, Berkeley, CA.

Copper has been observed to passivate in CMP slurries containing glycine, when hydrogen peroxide is used as an oxidant, even under acidic conditions where no solid oxidized phases appear on the potential-pH diagram. This passivation behavior is highly desirable for effective CMP. In contrast, passivation is not seen in slurries of similar pH and complexing agent concentration, where the potential is increased electrochemically. In order to model the effects of chemistry on CMP rates, we are endeavoring to better understand the mechanisms responsible for passivation in slurries containing hydrogen peroxide. Here we report tests that characterize the degree of passivation seen in slurries with a reasonably wide range of compositions. Copper surfaces exhibiting passivation have also been characterized ex-situ, microscopically and spectroscopically. These results are reported.

10:45 AM F6.6
THE pH INFLUENCE IN CHEMICAL MECHANICAL PLANARIZATION OF COPPER. Tianbao Du, Vimal Desai, Ying Luo, University of Central Florida, Advanced Materials Processing and Analysis Center, Orlando, FL.

The present study explores the effect of pH on the chemical mechanical polishing (CMP) characteristics of copper in H_2O_2-based slurry under various dynamic and static conditions. High purity copper disc was used to study the dissolution and oxidation kinetics under static and dynamic conditions at various pH (2 to 10) under various H_2O_2 concentrations. Electrochemical techniques were used to investigate the dissolution/passivation behavior of Cu. The affected surface layers of the statically etched Cu-disc were investigated using X-ray photoelectron spectroscopy (XPS) and scanning electron microscopy (SEM). The surface planarity was studied by atomic force microscopy (AFM). The Cu removal rate decreases with an increase in pH and reaches minimum at pH 6, and then increases under alkaline condition. XPS results indicate that the surface oxide formed at various pHs was responsible for this CMP trend. At pH 4, the copper removal rate reaches the maximum with 1% H_2O_2 concentration, and then decreases with the further increase of H_2O_2 concentration. In-situ electrochemical measurements indicate that the removal of copper is the result of mechanical abrasion of copper at low H_2O_2 concentration, while the role of the chemical etchant is to dissolve the material abraded from the surface. However, with the increase in H_2O_2 concentration, the oxidation rate of copper is fast and the removal mechanism changes to mechanical abrasion of oxidized Cu surface.

11:00 AM F6.7
INVESTIGATING THE ROLE OF CHEMICAL COMPONENTS IN COPPER CMP SLURRIES. Venkata R Gorantla and S.V. Babu, Dept of Chemical Engineering, Center for Advanced Material Processing, Clarkson University, Potsdam, NY.

Copper chemical mechanical planarization 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 at low down force has increased with the integration of Copper and Low-k dielectrics. This makes Copper CMP more to be a chemistry-driven process rather than a mechanically dominated one, requiring the investigation of different chemical components in the slurry. We investigated the role played by 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 dissociation constants of these 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.

11:15 AM F6.8
SLURRIES FOR COPPER DAMASCENE PATTERNING: SIMILARITIES AND DIFFERENCES. A. Jindal, G. Rajagopalan, M. Gupta, J.-Q. Lu, K. Rose, and R.J. Gutmann.

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 liner alone (selective) or the remaining copper and the liner in the field region (and possibly the ILD) at 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 alumina or silica abrasives) have been evaluated for dishing, erosion and post-CMP surface quality using single-level damascene patterns on 125 mm and 200 mm 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 um 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 zeta potential with capillary hydrodynamic fractionation (CHDF) and electrokinetic sonic amplitude (ESA) techniques. Correlation of slurry properties with damascene patterning metrics will be presented and discussed.

11:30 AM F6.9
POLISHING BEHAVIOR OF INTERLAYER FILMS IN Cu DAMASCENE PROCESS WITH DIFFERENT BARRIER AND Cu SELECTIVE SLURRIES. A.K. Sikder, University of South Florida, Center for Microelectronics Research, Tampa, FL; Parshuram Zantye 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 wiring process in integrated circuit (IC) manufacturing. Each silicon wafer may be exposed to 15 or more CMP steps before final device assembly. Understanding the basics 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 mechanical 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 (SiO_2, SiC, low-k B, low-k C, SiLK^{TM}, Ta and Cu) and discuss their 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 platen rotation. An acoustic sensor, attached with the substrate carrier, was used to monitor the process, and the signal was recorded in order to see the difference in polishing behavior of these coatings. The acoustic emission (AE) signal was found to increase with the higher platen velocity and pressure. In Cu damascene process, during Cu polishing, all the other interconnect layers (dielectric, cap, and barrier layer) are exposed to the slurry and this causes unwanted material removal and surface damage. In the case of ultra low-k materials delamination or cohesive failure could happen during this period. These issues are discussed in detail in this paper.

11:45 AM F6.10
THE COMBINATORIAL INFLUENCE OF INHIBITORS AND COMPLEXING AGENT IN Cu CMP. Ying Luo, Tianbao Du, Vimal Desai, 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 electro-migration resistance. Integration of copper into an IC manufacturing process can be implemented 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 statically etched Cu were investigated using X-ray photoelectron spectroscopy (XPS) and scanning electron microscopy (SEM). The surface planarity was studied by atomic force microscopy (AFM). The addition of glycine at acidic pH slurries does not enhance the Cu CMP removal but at basic pH, the CMP removal rate was significantly increased. The surface planarity of Cu at basic pH is improved by the addition of 3-amino-1, 2, 4triazole (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 24, 2003
Golden Gate B3 (Marriott)

1:30 PM *F7.1
MECHANICAL MODELING OF DISHING IN COPPER CMP. C. Fred Higgs III, Inho Yoon, Sum Huan Ng, LipKong Yap, Steven Danyluk, Georgia Institute of Technology, Woodruff School of Mechanical Engineering, Atlanta, GA; Zhiping 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-ambient pressure develops in the slurry during polishing. Dishing occurs in CMP processes when the copper-in-trench 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 F7.2
A NEW CLEANING TECHNIQUE FOR CORROSION PROTECTION IN ALUMINUM METALLIZATION. Masako Kodera[a,c], Yoshitaka Matsui[a], Naoto Miyashita[a,c], Manabu Tsujimura[b], and Shin-ichiro Uekusa[c]. [a]Toshiba Corporation, Yokohama, JAPAN; [b]Ebara Corporation, Fujisawa, JAPAN; [c]Meiji University, Kawasaki, JAPAN.

A new cleaning technique using gas dissolved water has been found to be effective to protect corrosion in Al metallizaion, 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 a surface potential of various metal films and to 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 post-cleaning of Al CMP using gas dissolved water instead of DIW is successfully protected corrosion. 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, anode water generated at the anode of the electrolytic cell has an ORP(oxidation reduction potential) of +200 to +400mA vs Ag/AgCl and contains oxygen gas, while cathode water generated at the cathode has an ORP of -500 to -700mV vs 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 in DIW, while that is greatly decreased in gas dissolved water.

2:15 PM F7.3
DELAMINATION BEHAVIOR OF Cu–LOW-k STACK UNDER DIFFERENT SLURRIES AND ABRASIVE DENSITIES IN SLURRY. A.K. Sikder, University of South Florida, Center for Microelectronics Research, Tampa, FL; Parshuram Zantye, University of South Florida, Department of Mechanical Engineering and Center for Microelectronics Research, Tampa, FL; S. Thagella, 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 parasitic capacitance, 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, the International Roadmap for Semiconductors (ITRS) predicts 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 rotation of platen (0.2 to 1.5 m/s) and down force (1-6 psi). Friction co-efficient 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 *F7.4
INTEGRATION CHALLENGES FOR CHEMICAL MECHANICAL POLISHING OF Cu/LOW k INTERCONNECTS. Mansour Moinpour, Jeffrey A. Lee, Thomas J. Abell, Intel Corporation, Santa Clara, CA.

The drive for improved performance of microelectronic devices has led to the prevalence of copper metallization and the aggressive development of low-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 $K<2.2$, presents numerous challenges for integration and 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 debonding, and are more susceptible to chemical and 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 resulting 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 processes and consumables that are material specific must be designed for compatibility with porous low-K materials. In addition, new planarization techniques must be explored as viable alternaives to conventional technologies. The present paper will discuss the general integration challenges and key reliability issues for chemical mechanical polishing of Cu/Low-K interconnects incorporating ultra low-K (porous) dielectric materials.

3:30 PM F7.5

INTEGRATED CHIP-SCALE PREDICTION OF COPPER INTERCONNECT TOPOGRAPHY. Tae Park, Tamba Tugbawa, Hong Cai, Xiaolin Xie, and Duane Boning, Microsystems Technology Laboratories, MIT, Cambridge, MA; Chidi Chidambaram, Chris Borst, and Greg Shinn, 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.