SYMPOSIUM W

Chemical-Mechanical Planarization–Integration, Technology, and Reliability

March 28 - 31, 2005

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* Invited paper

TUTORIAL

Recent Advances in Chemical Mechanical Planarization Technology
Monday March 28, 2005
10:00 AM - 5:00 PM
Room 2024 (Moscone West)

The tutorial on CMP is destined to give a cursory overview of the recent advances in different aspects of the CMP process. The tutorial will consist of an introduction to the novel findings and approach for various components of the CMP process. The improvements in CMP equipment, along with the innovative accessory modules attached, will be discussed. The CMP process has gone through several changes in the methodologies of process optimization and characterization. This process optimization and metrology aspect will be dealt with at length. The market for CMP consumables is steadily growing. Recent development in CMP slurries and the complex interplay of the slurry chemicals, additives, and their corresponding effect on the CMP process will be elucidated. The progress in modeling of the CMP process and transforming it from an art to a science will be reviewed. The issues such as mechanism of polishing, effect of different primary parameters such as pressure, relative linear velocity, particle side, pattern density etc. along with secondary parameters such as slurry flow, slurry viscosity, particle-size distributions, and aspect ratios in the pattern will be covered. The occurrence of defects due to a variety of reasons has been a teething concern of the CMP engineers and scientists. This issue will be addressed appropriately when the different facets of the CMP process are discussed. Finally, the tutorial will conclude with a discussion on the material reliability, feasibility, and CMP integration issues for current and future generation novel materials in different CMP applications.

Instructors:
Mike Oliver
Tom Tucker, Laredo Technologies
S. V. Babu, Clarkson University
Duane Boning, Massachusetts Institute of Technology
David Evans, Sharp Laboratories

SESSION W1: Copper CMP

Chairs: Earl C. Johns and Ingrid Vos
Tuesday Morning, March 29, 2005
Room 2024 (Moscone West)

8:30 AM *W1.1

Material Removal Mechanisms During Planarization of Cu and Ta Films: Role of Slurry Components. S. V. Babu, [1]Clarkson University, Potsdam, New York; [2]Center for Advanced Materials Processing, Clarkson University, Potsdam, New York.

As the feature sizes in silicon logic and memory devices continue to shrink, the speed and reliability of the interconnect wiring and circuitry have become increasingly significant. While both of these factors have benefited with the adoption of copper as the interconnect metal, the use of lower dielectric constant materials poses severe processing challenges, especially during the chemical-mechanical planarization (CMP) process. From the perspective of the CMP slurry, these challenges can be met with an improved understanding of the roles played by its different constituents like oxidizers, complexing and passivating agents, surfactants, etc., and the abrasives This presentation will review at a fundamental level the recent advances made in understanding Cu and barrier material removal mechanisms. The interactions between various functional groups in the slurry additives, pH, surface film characteristics, electrostatic charges, slurry transport, and abrasive particle adhesion and removal willbe described. Many of these characteristics can be tailored to enhance the chemical reactivity of the slurry without increasing defects while also controlling metal line thinning. Such an optimization will facilitate the proper balancing of the chemical and mechanical components during film removal, an essential step to the successful processing of Cu/barrier films with porous and mechanically weak low dielectric constant materials in the interconnect wiring structures.

9:00 AM W1.2

Soft Chemical Mechanical Polishing of Copper Based on Iodine Chemistries. Rajiv Singh[1,2], Marie Dufourg[3], Deepika Singh[3] and Suho Jung[2]; [1]University of Texas, Austin, Texas; [2]University of Florida, Gainesville, Florida; [3]Sinmat Inc, Gainesville, Florida.

Commercial copper CMP processes typically use hydrogen peroxide oxidizer which forms a relatively hard copper oxide layer, thus requiring high mechanical stresses and large particles to achieve acceptable removal rates. However, this high shear and normal stresses can damage the ultra low k dielectrics, which are expected to be commercialized within the next 3 -5 years. To address this challenge, we have developed a gentle copper/ultra low k CMP polishing process based on iodine chemistry. This results is formation of a much softer surface layer than conventional copper oxide, thereby allowing facile integration of soft fragile materials such as ultra low k dielectrics. By combining this chemistry with unique low defectivity nanoparticles further improvement in performance of dielectrics can be expected. This talk will present recent results on copper polishing using this unique chemistry. Novel integration schemes based on this chemistry will also be presented.

9:15 AM W1.3

Effect of Corrosion Inhibitor (BTA) in Citric Acid Based Slurry on Cu CMP. InKwon Kim, Dae-Hong Eom, Young-Jae Kang, Ja-Hyung Han and Jin-Goo Park; Engineering Bldg 1, Hanyang Univ., Ansan-si, Gyungki-do, South Korea.

Copper dishing and oxide erosion affect the final conductor thickness and the planarity of the wafer surface. It is important to control dishing and erosion during damascene process. These issues can be achieved by the addition of an inhibitor to the slurry. The adsorption behavior of BTA is strongly influenced by the slurry chemistry and abrasive type. BTA is adsorbed on Cu as well as abrasive particle. However, effect of BTA adsorption on particle is poorly understood in terms of removal rate and dissolution of Cu. In this study, the effect of BTA on polishing behavior was investigated as a function of H_2O_2, pH and abrasive particles. The removal rate, etch rate and friction force were measured using a friction polisher (Poli-500, G&P Tech) in citric acid based slurry with and without BTA. The adsorption behavior of BTA on slurry particles was analyzed by FT-IR and UV/VIS spectroscopy. Electrochemical properties of BTA film in various slurries were also measured using EG&G 273 potentiostat. The removal rate of Cu decreased and friction force increased in BTA added slurry. However, a higher removal rate was measured even with BTA in slurry at higher H_2O_2 concentrate than 10 vol% and pH 6.

9:30 AM W1.4

A Comparative Study of the Chemical Mechanical Planarization (CMP) of Copper in Slurries Containing Different Oxidizers and Complexing Agents. Vimal Desai, Advanced Materials Processing and Analysis Center, University of Central Florida, Orlando, Florida.

Chemical Mechanical Planarization (CMP) is one of the most important techniques for damascenes interconnect processing, where CMP has been used to remove the overburden material and planarize the wafer surface. 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. Thus integration of copper into an IC manufacturing process can be implemented by using the dual Damascene technique, in which CMP has been applied. 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 a mechanically dominated one, requiring the investigation of different chemical components in the slurry. This study aims to improve our understanding of the removal mechanism during copper CMP using different oxidizer based slurries, where the oxidizers such as hydrogen peroxide and ammonium persulfate were selected for this study. The effect of oxidizer, complexing agent and inhibitor at various pH were studied through potentiodynamic polarization, in-situ open-circuit potential, in-situ linear polarization resistance, and potentiostatic techniques. 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 CMP mechanism with the addition of inhibitor and complexing agents at various pH was also investigated.

9:45 AM W1.5

Effect of Temperature on the Chemical Mechanical Polishing (CMP) Slurry Abrasive Particle Agglomeration and Defectivity. S. Mudhivarthi[1,2], Parshuram Bakrishna Zantye[1,2], Arun Kumar[2], Ashok Kumar[1,2], Jeung-Yeop Shim[3] and Edward Turos[3]; [1]Mechanical Engineering, University of South Florida, Tampa, Florida; [2]Nanomaterials and Nanomanufacturing Research Center, University of South Florida, Tampa, Florida; [3]Department of Chemistry, University of South Florida, Tampa, Florida.

To meet the increasing demand for smaller and faster devices, Multilevel Metallization (MLM) is being implemented. Chemical Mechanical Planarization (CMP) is the process of choice for planarization of the constituent layers of the MLM. Besides having a lot of advantages, there are numerous defects associated with the CMP process such as delamination, microscratches, dishing, erosion etc. The occurrence of (nano, micro and macro) scratches on the polished surface may severely degrade the surface quality thereby hampering the device output. Particle size plays a major role in generating surface scratches. Agglomeration of abrasive particles is the main cause for alteration in slurry particle size distribution. In this research, the effect of slurry temperature on the slurry abrasive particle agglomeration and its impact on the polished surface is studied. Intentional agglomeration of slurry particles is carried out to magnify the effect of agglomerates. Change in particle size distribution with concentration of agglomerating agent and temperature is analyzed using Particle size distribution analyzer. CMP of Cu using slurry with high concentration of agglomerating agent at various temperatures is carried out for constant down force and relative linear velocity. Post CMP metrology is carried out using Atomic force microscopy (AFM), to characterize the variation in scratch density, scratch depth and roughness of the wafer sample at different temperatures. The primary goal of this study is to gain deeper understanding of the effect of heat generation and rise in temperature at the pad wafer interface on agglomeration of the slurry abrasive particles and resulting surface defects.

10:00 AM W1.6

Potential-pH Diagrams of Interest to Chemical Mechanical Planarization of Copper Thin Films. Serdar Aksu, Engineering, Suleyman Demirel Univeristy, Isparta, Turkey.

Chemical mechanical planarization (CMP), which can globally planarize both silicon dioxide (the prevalent interlayer dielectric), and copper films, has become the key process in the damascene method used for producing integrated circuit devices with multilevel copper interconnects. Copper CMP is typically carried out with slurries containing oxidizing agents, complexing agents, and corrosion inhibitors as the principal chemical components. In such slurries, complexing agents enhance the solubility of copper and increase the dissolution rate of the abraded material in copper CMP. In addition, they help achieving high copper removal rates during dynamic polishing conditions. The nature of the complexing agent used, the pH and the redox potential of the slurry system are among the main factors controlling the dissolution and passivation behavior of copper during CMP. Consecutively, these factors are intimately related to the key CMP performance metrics such as removal rate and planarity. In this paper, potential-pH diagrams of copper in aqueous systems containing a number of organic complexing agents including ethylenediaminetetraacetic acid (EDTA), nitrilotriacetic acid (NTA), oxalic acid and malonic acid are presented. The predominance regions of copper complexes under different copper and ligand concentrations and their implications on copper removal during CMP are discussed.

10:30 AM *W1.7

Investigation of Abrasive Free Copper Chemical Mechanical Planarization Process for Cu/Low k and Cu/Ultra Low k Interconnects. Subramanian Balakumar, Tabassumul Haque, Thangavelu Selvaraj and Rakesh Kumar; Semiconductor Process Technology Lab, Institute of Microelectronics, Singapore, Singapore.

For highly miniaturized and high performance Integrated Circuits (ICs), copper interconnects are being used with low-k dielectrics. Low-k dielectrics make chemical mechanical planarization (CMP) process very challenging as low-k dielectric materials are mechanically weaker than conventional silicon dioxide dielectrics. In order to maintain the integrity of the damascene structure, use of low-stress CMP process is necessary. One of the low stress CMP processes is abrasive free CMP process which is being used now for Cu/ultra low k (k-2.4) materials. However there are many challenges in optimizing the low pressure CMP process and the material removal (wear) mechanism need a better understanding. In this study, to understand the material removal mechanism, different process conditions were used to polish the copper blanket wafers using abrasive free Cu slurry and the variation in the surface morphology due to different wear mechanisms was observed. The average copper removal rate of 6000 A/min with within wafer non uniformity (WIWNU) of less than 3 % was achieved using low pressure (1.5 psi). Since abrasive free slurries are highly chemically active slurries, complex formation rate is very high and it is also pattern dependent. Removal of such layer on the patterned wafer required minimum pressure to clear the copper, which is defined as lower critical pressure. Detailed studies have been carried out to identify the process window. Dishing control was achieved during Cu polish using different carrier/platen speed in Cu/Oxide and Cu/SiLK patterned wafers. Based on these studies, an abrasive free slurry CMP process was developed for use in for Cu/low k and Cu/ultra low-k integration process. The cumulative distribution of the metal line-to-line leakage current measurements of wafers shows good performance and it is comparable to abrasive process. Post CMP defects were also carried out and found chatter marks, metal line delamination due to barrier polish. Detailed results will be discussed.

11:00 AM W1.8

A Comparative Study of the Performance of Copper CMP Slurries for their Relative Sensitivity to Environmental Temperature Variations. Yuzhuo Li[1], Krishnayya Cheemalapati[1], Deenesh Bundi[1], Vivek Duvvuru[1], Lily Yao[2], Kwok Tang[3] and Wu Li[3]; [1]Chemistry, Clarkson University, Potsdam, New York; [2]Strasbaugh, San Luis Obispo, California; [3]Dynea, Mississauga, Ontario, Canada.

With the integration of copper as interconnect and low k materials as dielectric, the CMP community is facing an ever increasing demand on reducing defectivity without scarifying production throughput. It is thus fundamentally important to understand the impact of every key input processing parameters on polishing performance. Tremendous effort and progress have been made on the correlation between slurry performance and key mechanical processing parameters such as down force, back pressure, table/spindle speeds, flow rate, etc. It is also widely recognized that the slurry and pad temperature plays a significant role on the critically needed balance between the chemical and mechanical strengths of a copper CMP slurry. There are, however, only very limited investigations on a systematic comparison among slurries with different abrasive particles and formulation chemistry for their relative sensitivity toward environmental temperature. Moreover the temperature effect on the slurry performance such as step height reduction efficiency, final dishing and erosions, and other surface defects are relative unexplored. In this study, a set of copper CMP slurries that are prepared with different abrasive particles and chelating/passivating chemistry are investigated for their relative response toward environmental temperature change. More specifically, the relative material removal rate, step height reduction efficiency, final dishing and erosion values, and other surface defects are compared among these slurries with or without environmental temperature perturbation. The potential value of this study is to offer the CMP community a more comprehensive yet simple guideline for the formulation of advanced copper CMP slurry. In this presentation, the physical and chemical characteristics of these slurries will be presented first. Blanket and patterned wafer polishing results using slurries formulated based on these particles will be introduced. The relative sensitivity of these slurries will be compared. Finally the potential advantages of properly controlling the slurry and pad temperature for the copper low k integration scheme will be examined.

11:15 AM W1.9

The Adhesion of Pad Particles on Wafer Surfaces during Cu CMP. Jae-Hoon Song[1], Ja-Hyung Han[1], Dae-Hong Eom[1], Yi-Koan Hong[1], Young-Jae Kang[1], Jin-Goo Park[1], Ju-Ho Maeng[2] and Young-Man Won[2]; [1]Hanyang Univ., Ansan, Gyungki-do, South Korea; [2]Saesol Diamond, Ansan, Gyungki-do, South Korea.

Abraded pad particles can be generated during pad conditioning in CMP process. If they exist on pad, they can be strongly adhered on wafers because of the stress and higher temperature during polishing. In this study, the adhesion and removal of pad particles were theoretically and experimentally investigated during Cu CMP process. The zeta potentials of pad particles and wafers were measured as a function of pH. In order to obtain the large amounts of pad particles, original pad was severely polished on purpose by diamond disk without any solutions. Cu and Ta particles were used instead of Cu and Ta wafers due to the high conductivity of these surfaces. The zeta potentials of substrates of the TEOS, Aurora, SiLK and FSG were also measured. The isoelectric point (IEP) of pad particles was measured to be around pH 3. Most wafer surfaces showed the negative zeta potentials at the pH ranges investigated with the exception of FSG and Ta. The theoretical interaction forces between the pad particle and wafer surfaces were calculated based on the DLVO theory at acidic, neutral and alkaline pH ranges. The strongest attraction force was calculated in acidic solution. On the other hand, the weakest attractive force was calculated in alkaline solution. The adhesion force between pad particles and wafer surfaces was measured in acidic, neutral and alkaline solution by an Atomic Force Microscope (AFM, CP Research, Park Scientific Instruments). The pad particle was attached on Si_3N_4 tipless cantilever. The lowest adhesion force was measured in alkaline solution due to the lowest negative zeta potential of surfaces.

11:30 AM W1.10

Novel Use of Surfactants in Copper Chemical Mechanical Polishing. Youngki Hong[1], Udaya B. Patri[2], Suresh Ramakrishnan[2] and Babu S. V.[2,3]; [1]Engineering Science, Clarkson University, Potsdam, New York; [2]Chemical Engineering, Clarkson University, Potsdam, New York; [3]Center for Advanced Materials Processing, Clarkson University, Potsdam, New York.

Surfactants have been used as one of the components of the chemical mechanical polishing (CMP) slurries primarily for improving the slurry stability. Ionic surfactants (anionic and cationic) when used in a typical CMP slurry can also interact with the film being polished through electrostatic attraction and repulsion. Copper films develop charges on their surface when in contact with an aqueous slurry with the magnitude and the sign of the charges dependent on the composition and the pH of the slurry. Ionic surfactants having a charged hydrophilic head group and a hydrophobic tail, when used in copper CMP slurries can interact with the charged copper films. With proper choice of the slurry system, these interactions can be useful for CMP applications. In this study, Sodium Dodecyl Sulfate (SDS), one of the conventional anionic surfactants was examined as an alternative to Benzotriazole(BTA) as an inhibiting agent of copper dissolution in a model copper CMP slurry consisting of 5 wt% hydrogen peroxide, 1 wt% glycine and 3 wt% fumed silica abrasive. Compared to BTA, SDS shows better performance in controlling copper dissolution rates. Copper dissolution rates are completely shut down to $\sim$1 nm/minute just with the addition of 1 mM SDS to the chemical solution at pH $\sim$ 4. The electrostatic attraction between the copper surface and the surfactant at this pH results in the surfactant adsorption on to the copper surface, forming a protective layer that prevents the interaction of the chemicals with the copper surface. Contact angle measurements of the copper surface exposed to the slurry and after polishing confirm that the surface is hydrophobic indicating the adsorption of the surfactant. At higher pH values, since both surfactant and copper surface have same charge, the adsorption does not occur and the dissolution rate of copper remains high. The results of the dissolution and polish experiments along with the proposed mechanism and their impact on copper line dishing will be presented and discussed.

11:45 AM W1.11

Role of Molecular Structure of Complexing/Chelating Agents in Copper CMP Slurries. Udaya Bhaskar Patri and S. V. Babu; Chemical Engineering, Clarkson University, Potsdam, New York.

Copper dual damascene process coupled with chemical mechanical planarization (CMP) of over burden copper has emerged as the only viable technique for patterning copper lines in the manufacture of Ultra Large Scale Integration (ULSI) based devices. With the introduction of low-k dielectric materials, integration of cu/low-k dielectrics has become a challenge due to the weak mechanical properties of the low-k materials. In order to overcome this problem, copper CMP process needs to be performed at low pressures. If throughput is not to be sacrificed, this calls for increasing the chemical activity of the CMP slurries. A better understanding of the roles of various chemicals used in typical copper CMP slurries along with the search for novel chemicals is required to achieve this goal. Typically copper CMP slurries are composed of an oxidizer, the most preferred one being hydrogen peroxide (H2O2), a corrosion inhibitor like benzotriazole (BTA), a complexing/chelating agent and other additives along with abrasives like silica and alumina. Glycine has been studied as a complexing/chelating agent along with citric acid, ethylene diamine, ethylene diamine tetra aceticacid etc. However, there has been no clear understanding of the role of the molecular structure - role of different functional groups (eg; NH2 vs. COOH), their relative positions, the length of the carbon chain and the type of bonds between different carbon atoms - of the complexing agents in controlling the material removal rates. In this study, several complexing agents containing amine and/or carboxyl groups (acetic acid, succinic acid, ethylene diamine, glycine, alanine, amino butyric acid and others) have been studied to understand better the role of the molecular structure in determining copper removal rates. It was observed that the relative positions of the functional groups (i.e. -NH2 & -COOH) in a complexing agent effect the type of complex formed and hence the removal rates. The results of the experiments and the proposed mechanism will be presented and discussed.

SESSION W2: CMP Equipment and Metrology
Chairs: S. V. Babu and Yaw Obeng
Tuesday Afternoon, March 29, 2005
Room 2024 (Moscone West)

1:30 PM *W2.1

Feasibility of Real-Time Detection of Abnormalities in Slurries during CMP via Frictional Signature Analysis. Ara Philipossian[1], Yasa Sampurno[1], Manish Keswani[1], Yun Zhuang[1] and Michael Goldstein[2]; [1]Chemical Engineering, University of Arizona, Tucson, Arizona; [2]Fab Materials Operation, Intel Corporation, Santa Clara, California.

This work will explore the feasibility of using real-time shear force analysis during CMP to determine whether an 'out-of-spec' slurry (i.e. in terms of the extend and the size of its hard or soft agglomerates as well as other structures created by chemical and mechanical interactions of silica aggregates, or left in the slurry through poor filtration) can be effectively screened and thus be prevented from being used in IC manufacturing. The frictional signature can be broken up into three levels of understanding as follows: (1) Mean frictional measurement, which indicates the average removal rate of the process and the average life of the polishing pad. The former can be used to estimate the polishing time required, while the latter is useful for improving tool availability and hence factory productivity, (2) variance of the frictional signature, which indicates the lubrication regime of the polishing process. 'Boundary Lubrication' is characterized by large variances, while 'Hydrodynamic Lubrication' is indicated by very low variances. As expected, 'Mixed Lubrication' results in intermediate variances. Pad life is very sensitive to the lubrication regime, with boundary lubrication resulting in the lowest pad life, and (3) frequency decomposition of the frictional shear force, which gives more in-depth insight into the interaction between abrasive particles (aggregates and agglomerates), the pad and the wafer. In fact, each combination of pad, slurry, and wafer should have a unique spectral 'fingerprint', which can be used to monitor the polishing process in real-time. This work will systematically attempt to determine whether one can: (A) distinguish the slurry, pad and wafer pattern effects from the spectral fingerprint, (B) detect the formation of a defect on the surface of the wafer, (C) observe the fracture of large particles into smaller particle during shearing in the pad-wafer region, (D) differentiate between primary particles, aggregates, soft agglomerates and hard agglomerates with this measurement, and (E) use this novel methodology to aid slurry or IC makers in screening the material before shipment or use.

2:00 PM W2.2

An Online Strategy for End Point Detection in CMP through Multiresolution Analysis of CoF Data. Tapas K. Das[1], Alok Buch[2], Rajesh Ganesan[3], Ashok Kumar[4] and Arun Sikder[5]; [1]Department of Industrial & Management Systems Engineering, University of South Florida, Tampa, Florida; [2]Industrial & Management Systems Engineering, USF, Tampa, Florida; [3]Industrial & Management Systems Engineering, USF, Tampa, Florida; [4]Mechanical Engineering, USF, Tampa, Florida; [5]GE Research, Bangalore, India.

Efficient end point detection (EPD) in Chemical Mechanical Planarization (CMP) is critical to quality and productivity of the wafer fabrication process. The cost of over and under polishing, and the cost of ownership of many expensive metrology based EPD methods have motivated the researchers to seek cost effective and efficient alternatives. Recent literature contains several wavelet decomposition based multiscale process monitoring approaches including process monitoring applications, such as tool-life monitoring, bearing defect monitoring, and monitoring of ultra-precision processes such as chemical mechanical planarization (CMP) in wafer fabrication. However, all of the above mentioned wavelet based methodologies are offline. In an offline method, one can decompose longer data lengths to a larger number of levels in order to capture information needed for monitoring. This is computationally involved and needs longer processing time, which becomes a serious challenge in online (real time) applications. Moreover, high rate of data collection by the current sensors poses additional difficulty of matching data processing rate with the data acquisition rate, which makes it even more difficult to design a real time monitoring tool. This paper presents a novel method for end point detection, which uses a sequential probability ratio test (SPRT) on the wavelet decomposed coefficient of friction (CoF) data collected at a high frequency of 1KHz from the CMP process. The method is made suitable for online application by developing a moving block data processing strategy, which matches the rate of data acquisition. The methodology is also capable of displaying the analysis results through real time graphs for ease of process supervisory decision making. Tests on both oxide and copper metal CMP show that the developed methodology is uniquely capable of identifying the start and finish of the end point event

2:15 PM W2.3

Instantaneous Fluid Film Imaging in Chemical Mechanical Planarization. Daniel Apone[1], Chris Rogers[1], Caprice Gray[1], Vincent Manno[1], Chris Barns[2], Sriram Anjur[4] and Mansour Moinpour[3]; [1]Tufts University, Medford, Massachusetts; [2]Intel Corp, Hillsboro, Oregon; [3]Intel Corp, Santa Clara, California; [4]Cabot Microelectronics, Aurora, Illinois.

In this paper we present a technique for capturing instantaneous fluid film thickness measurements during an actual CMP polish. This non-invasive technique relies on principles of Dual Emission Laser Induced Fluorescence (DELIF) to image the fluid film region between a silicon wafer and the polishing pad. From these images, a deeper understanding of Pad/Wafer interaction is gained. The thickness measurements taken allow us to determine which lubrication regime each polishing run resides in. Friction measurements taken during these runs help show differences in the lubrication regimes. Features of the pad (asperities, conditioner striations) are observed with this technique, along with etchings made in the wafers to allow the measurement of asperity compression and rebound.

2:30 PM W2.4

Feasibility of Detecting Barrier Layer to Low-K Transition in Copper CMP Using Raman Spectroscopy. Siddartha Kondoju[1], Christophe Juncker[1], Pierre Lucas[1], Srini Raghavan[1], Paul Fischer[2], Moinpour Mansour[3] and Oehler Andrea[2]; [1]Materials Science and Engineering, University of Arizona, Tucson, Arizona; [2]Intel Corporation, Portland, Oregon; [3]Intel Corporation, Santa Clara, California.

In copper CMP, transition from copper to barrier as well as barrier to dielectric layer is typically sensed using an optical reflectance technique. With the introduction of carbon doped oxides (CDO) as dielectric materials, it is possible to sense the barrier to dielectric transition using spectroscopic techniques that are sensitive to carbon, hydrogen and silicon in CDO. This paper will present results of an investigation undertaken to explore the use of Raman spectroscopy in detecting the transition from Ta to CDO materials. An abrasion cell integrated with a Raman spectrometer has been used for the investigations. Intensities of Raman peaks characteristic of C-H and Si-Si vibrations have been used for detecting the transition. Capabilities and limitations of the Raman spectroscopic method will be discussed.

2:45 PM W2.5

AFM Measurements of Adhesion between Actual CMP Slurry Particles and Various Substrates. Igor Luzinov[1], Yong Liu[1], Bogdan Zdyrko[1], Alex Tregub[2], Mansour Moinpour[2] and Mark Buehler[3]; [1]School of Materials S&E, Clemson University, Clemson, South Carolina; [2]Intel Corporation, CMO/FMO, San Jose, California; [3]Intel Corporation, PTD, Portland, Oregon.

One of the critical parameters in chemical mechanical planarization (CMP) technology is adhesion between abrasive particles and surfaces being polished. Accumulated up to date theoretical and experimental facts insist that development of advanced material removal and cleaning methods requires understanding and evaluation of particle adhesion in these processes. To this end, the present communication focuses on AFM studies of interaction between the actual slurry particles and different substrates treated by CMP processes. Major goal of the research is to establish relationships between adhesion forces built up at slurry particle/treated material contact and material and particle removal in CMP and post-CMP processes, respectively. To conduct adhesion measurements, the particles present in a CMP system and model latex particle were first attached to the surface of silicon wafer covered with monolayer of polymer(s) having high affinity to particles and the silicon wafer. For this purpose ultrathin (1-5 nm) poly(vinyl pyridine) (PVP) or PVP/poly(glycidyl methacrylate) blend interlayers were deposited on the substrate by dip-coating or adsorption from solution. Adsorption of different slurry particles on the wafers covered with the layers was studied. Slurry concentration, adsorption time, and type of agitation were varied to identify the best conditions for the fabrication of samples uniformly covered with the adhered particles. The utilization of adsorption technique allowed not only firm attachment of the particles to the surface, (what is extremely important for accurate adhesion measurements), but also evaluation of the state of their aggregation in the CMP and post-CMP systems. Indeed, since adsorptive activity of the polymer monolayer was strong enough, the particles attached to the surface reflected the actual situation in the system. Glass/quartz sphere (10-60 microns) was attached to AFM cantilever with appropriate spring constant. (The sphere represented the surface of material being polished and might be covered with various materials during future investigations.) Next, AFM force volume mode, which utilizes the collection of the force-distance curves over selected surface areas, was used for the adhesion measurements. The sphere was brought into multiple contacts with the wafer covered with the slurry particles and immersed in a liquid. When the AFM cantilever withdrew from the contact with a sample surface, an adhesion force developed between the sphere and slurry particles. The removal forces were measured over 20x20 microns area to estimate the adhesion situation in the system. Dependence of the adhesion forces on particle nature and liquid environment has been investigated employing the developed experimental procedures. Preliminary results on latex particle showed that method allows determination of small changes in the adhesion, if PH of the liquid media was changed.

3:30 PM *W2.6

Abrasive Contribution to CMP Friction. Michael R. Oliver[2] and David R. Evans[1]; [1]Sharp Laboratories, Camas, Washington; [2]Portland, Oregon.

Friction in the CMP process is a subject of ongoing interest. The sources of friction can be the viscosity of the slurry between the pad and wafer, as well as the physical contact between the pad asperities and the wafer. The contact between the pad and the wafer can be direct or also through slurry particles trapped between the pad asperity and the wafer. We measure the friction between the wafer and the pad by measuring the CMP table current and subtracting out the background level. This is done for different concentrations of silica abrasive between 0 and 13%, as well as for different pressures and table speeds. Two widely different types of silica particles used in CMP are spherical colloid particles and aggregated fumed particles. We also compare the resultant friction behavior by comparing the results for both types of particles. For different abrasive contributions, the friction measurements are compared to the CMP removal rates. This evaluation is also done with a stationary wafer carrier, so that the observed removal rate at a specific point on the wafer is proportional to the local pressure on the wafer. The wafer carrier used for these tests uses a gimbal design. In this case the pressure at the leading edge of the wafer is larger than that at the trailing edge. From these studies we find that, for gimbaled systems with grooved pads, the friction is primarily caused by pad-asperity contact, and the addition of slurry particles does significantly change the friction interaction in the CMP process. Further, the non-uniformity in friction across the wafer is controlled by the pad surface structure and mechanical design of the CMP tool.

4:00 PM *W2.7

A Simplified XRD Line Profiling Technique to Characterize the State of Stress on Post-CMP Copper Films. Pradip K. Roy[1], Edward Hwang[1] and Manish Deopura[2]; [1]Neopad Technologies Corporation, Sunnyvale, California; [2]MIT Microsystems Technology Laboratories, Cambridge, Massachusetts.

Copper CMP is typically done in three steps: bulk removal, soft landing, and barrier removal. Bulk removal, unlike the other two, uses high down force to achieve relatively higher material removal rate. During the bulk removal step, due to the high down force copper interconnects suffer from process induced stress. This process induced stress has both short-range and long-range components. While the short-range component is mostly removed during CMP, the long-range component of the stress remains stored within copper interconnects after CMP. This built-in stress in copper can have significant impact on device reliability in terms of stress voiding and stress-induced electro-migration. The increased stress level can also cause separation of weak interfaces that can not withstand high local stress. Therefore, the process induced stress should be minimized in the bulk removal step. Recent emergence of some derivative technologies such as ECMP and ECMD is a result due to these stress problems. However, these expensive technologies are yet to be fully understood and developed. In this regard, we have designed a novel sub-surface engineered and stress-accommodated pad that generates low shear force, thus reducing the process induced stress in copper. This paper discusses an XRD peak profiling technique to evaluate the state of stress. We have employed Cu-Kα radiation using a Rigaku diffractometer for measurements. We use the dominant copper reflection (111) and its higher angle harmonic (222) reflection for peak profiling. A shift in the peak position reflects to a change in the lattice constant or band structure and is a measure of the built-in stress. The nature of stress is dictated by the direction of the shift, and the amount of the shift is proportional to the induced stress level in copper. A change in the integral peak width is a measure of crystallite subgrain size and microstrain associated with these crystallites. In this study, three different kinds of pads are evaluated for copper CMP using the same process conditions for bulk copper removal. XRD line profiling is done on these polished copper wafers. Lattice constants and peak widths are calculated based on the peak from the (222) reflections. Relative peak shift and broadening of polished copper wafers are compared with the (222) peak position and width of an unpolished copper wafer. (222) peak position and lattice parameters data with Neopad proprietary pad indicate virtually no change in lattice constant. In comparison, the other two commercial pads show a significant change in lattice parameter and peak shift. There are no significant changes in peak width for polished wafers by all three pads. This XRD line profiling method is used extensively in most front-end process module for process qualification and optimization. Importance of this built-in stress after CMP, which has become critical for interconnect reliability, makes this XRD line profiling appealing.

4:30 PM W2.8

Effect of Particle Size Distribution on Filter Lifetime in Three Slurry Pump Systems. Mark R. Litchy[1] and Reto Schoeb[2]; [1]CT Associates, Inc., Bloomington, Minnesota; [2]Levitronix GmbH, Zurich, Switzerland.

Slurries, suspensions of fine particles dispersed in a liquid, are often used in semiconductor chip manufacturing to planarize wafer surfaces. The effectiveness of these slurries in achieving a flat surface free of scratches is highly dependent upon the physical properties of the slurry. Perhaps the most important physical properties of the slurry are the size of the fine or working particles in the slurry and the presence of large particles, often referred to as the large particle tail, which can cause scratches. Delivery systems are often used to supply the slurry to the planarization tools. These systems pressurize the slurry to deliver it to the tools and circulate it to keep the particles in suspension. Pressurization and circulation are accomplished by various means including a variety of pumps and pressure-vacuum technology. Typically, the slurry passes through the slurry distribution systems approximately 100 times before it is used to polish wafers. Many shear sensitive slurries are easily damaged by mechanical handling. Damage often takes the form of changes in the size distribution of the slurry particles. In a previous study, experiments were performed to determine the effect of circulating Semi-Sperse® 12 (Cabot Microelectronics Corporation) with three different types of pumps (bellows, diaphragm, and centrifugal) on the size distribution of the particles in the slurry. The size of the working particles (particles typically $\sim 0.1\ \mu$m in diameter that are performing the planarization) was measured with a NICOMP 380 ZLS Submicron Particle Sizer (Particle Sizing Systems) that determines particle size by dynamic light scattering. The particle size distribution (PSD) of the large particle tail was measured with an AccuSizer 780 optical particle counter (Particle Sizing Systems). Significant differences in the large particle tail of the slurry PSD were observed after circulation with three different types of pumps. Large particles that can scratch wafer surfaces are removed by filtration. The large particles tend to occlude the filter causing reduced flow rates and large pressure drops. Chemical-mechanical polishing (CMP) filters must be changed regularly, in some cases every few days. The frequency of filter change depends on many factors including the type of slurry, type of filter, pore size rating of the filter, etc. The increase in pressure drop across a filter determines the life of a filter. This paper describes the results of a study that was performed to determine if the changes observed in the large particle tail PSD as a result of pumping correlated to changes in the lifetime of filters used to remove large particles from the slurry. The increase in pressure drop across a Mykrolis Planagard™ CMP3 filter as a function of delivered slurry was characterized for three types of pumps. The expected results were observed: the higher the concentrations of large particles, the faster the filters clogged.

4:45 PM W2.9

A Universal CMP Process Description Language for Standardization. Takafumi Yoshida, Dept of TCAD, YNT-jp.com, Hikari, Yamaguchi, Japan.

This paper proposes a universal CMP process description language. We discuss the appropriate attributes to describe complex CMP processes and the capability for standardization of CMP.
We show an implementation of the language based on an open standard.

SESSION W3: CMP Pads

Chair: Jeffrey Lee
Wednesday Morning, March 30, 2005
Room 2024 (Moscone West)

8:30 AM *W3.1

CMP Polishing Pads: Metrology and Characterization Issues. Alexander Tregub, Dipankar Bose, Susan Holl Holl, Jim Mulready, Andrea Oehler, Reza Golzarian, Anthony Kim and Mansour Moinpour; CMO/FMO-CGO-Polymer Material Engineering Group, Intel Corporation, Santa Clara, California.

Chemical Mechanical Planarization (CMP) has emerged as the premier technique for achieving both local and global planarization in silicon integrated circuit manufacturing. The current momentum in integrating CMP as an enabling step into existing and new processes continues to exceed the fundamental understanding of the CMP polishing pad properties and their correlation to CMP processes. As a consequence, there is an apparent lack of a reliable matrix of the pad properties that would allow prediction of and direct correlation to the CMP performance. In turn, this creates a challenging environment for a robust process control system definition at the pad manufacturing step. Some of the challenges include establishing clearly defined key and control parameters for the supplier's manufacturing processes, reliable and robust metrology for measurement of key and control parameters, and establishing reliable material specification requirements for both incoming raw materials and finished product. In addition to improvements in the area of process control system, application of non-traditional or novel techniques and approaches for material characterization and quality control schemes need to be considered. In this paper, successful characterization of CMP pads was demonstrated using advanced thermoanalytical techniques, such as Dynamical Mechanical Analysis (DMA), Modulated Differential Scanning Calorimetry (MDSC), Thermal Gravimetric Analysis (TGA), Thermal Mechanical Analysis (TMA). The goals of these studies were to achieve better understanding of the fundamental properties of CMP polishing pads and propose mechanisms to improve pad performance. [1, 2]. In particularly, effects of pad temperature conditioning and pad exposure to slurries and DIW were studied for two types of CMP pads. Additionally, the results of bench mark pad characterization are reviewed. Using the results of the characterization studies, this paper outlines improvements in pad manufacturing, quality and process control, and performance predictability of CMP pads. REFERENCES 1. Moinpour M, Tregub A, Oehler A, Cadien K. Advances in Characterization of CMP consumables, MRS Bulletin, 2002, 27(10), 766-771 2. Tregub A, Ng G., Sorooshian J., Moinpour M. Thermoanalytical Characterization of Thermoset Polymers for Chemical Mechanical Polishing. Thermochimica Acta, in press.

9:00 AM W3.2

Functionally Graded Novel Chemical Mechanical Planarization Pads. Manish Deopura[1,2], Mohammed Nasrullah[2], Sudhanshu Misra[2], Edward Hwang[2], Hem Vaidya[2] and Pradip Roy[2]; [1]Materials Science & Engineering, MIT, Cambridge, Massachusetts; [2]Neopad Technologies Corporation, Sunnyvale, California.

Taking advantage of the versatile nature of the urethane chemistry, new chemical pathways have been developed to make Chemical Mechanical Planarization pads. Tribological, mechanical and thermal characteristics of these novel polyurethane pads have been studied and compared to commercial pads (IC-1000 and JSR Standard WSP). Stribeck curve studies for blanket ILD CMP applications have shown that the coefficient of friction value (COF) for novel pads is lower, indicative of greater pad life. COF as a function of the Sommerfeld number is more uniform indicative of a more stable process. Characterization of mechanical properties which includes hardness values and modulus values has been also carried out.In addition, a systematic study is performed to study the effect of pad fabrication temperature on the skin thickness and consequently the effect on conditioning time is studied. Skin thickness in these experiments is measured using cross-sectional optical microscopy. Further, functionally graded pads designs based on novel polyurethanes are used for polishing patterned wafers. Results indicate a higher planarization efficiency in comparison to commercial pads for pattern density values ranging from 10 to 90 per cent.

9:15 AM W3.3

Surface and Material Characterization of Psiloquest's Application Specific Pads (ASP) for Chemical Mechanical Polishing (CMP) Applications. Yaw Obeng[3], S. Mudhivarthi[1,2], Parshuram Bakrishna Zantye[1,2] and Ashok Kumar[1,2]; [1]Department of Mechanical Engineering, University of South Florida, Tampa, Florida; [2]Nanomaterials and Nanomanufacturing Research Center, University of South Florida, Tampa, Florida; [3]Texas Instruments, Dallas, Texas.

There is a need for extensive metrology to predict the performance of the CMP pads before putting them in to service. The Psiloquest's ASP is made up of condensed polyolefin coated with ceramic materials and the pad surface is tuned to match the mechanical properties of the target substrate. The evaluation of the effects of surface modification and chemical properties of the polyolefin pads with their CMP performance has been performed in the past and the results have been widely published. In this research, we have studied the effect of pad thickness and variation in the polyolefin materials on the CMP performance of the ASP. The 6 inch coupons of the pads were polished using CETR CP-4 bench top CMP tester to evaluate the dynamic coefficient of friction (COF), Acoustic Emission (AE) signal and removal rate. The 1 inch X 1 inch coupons of Si wafers having 6000 Å Tungsten film as polishing samples and Cabot W 2000 CMP slurry as polishing slurry were used for pad evaluation. The variation of COF, AE and CMP material removal rate (MRR) with pad thickness for different pad materials were the primary output parameters under study. Polishing experiments need to be performed on sufficiently large number of pads and each polishing run was repeated 5 times in order to get the statistical distribution of their tribological properties.

9:30 AM W3.4

Integration of CMP Fixed Abrasive Polishing into the Manufacturing of Thick Film SOI Substrates. Martin Kulawski[1], Hannu Luoto[1], Kimmo Henttinen[1], Tommi Suni[1], Jari Makinen[2] and Frauke Weimar[3]; [1]Microelectronics, VTT Information Technology, Espoo, Finland; [2]Okmetic, Vantaa, Finland; [3]3M Europe, Neuss, Germany.

The use of fixed abrasive (FA) pads for silicon and especially for silicon on insulator (SOI) chemical mechanical polishing (CMP) has been shown to be highly beneficial. As the specification for the total thickness variation (TTV) of the device layers constrict for future applications, especially the major or bulk removal polishing process after grinding cannot meet the demands in terms of flatness. This is due to the required amount of material removal for polishing out the induced sub surface damage (SSD) in combination with the unsatisfactory effectiveness of grind-line and topography removal, when using conventional, slurry driven CMP processes. Based upon the encouraging and further developed early results of FA pad use for silicon and SOI polishing, a complete manufacturing process sequence is presented and analyzed. Starting from low SSD grinding of the bonded SOI wafer couple, an optimized FA CMP step is replacing the conventional bulk polishing. By introducing also subsequent final and haze removal CMP, prime wafer quality surface is achieved on thick film SOI substrates. The surface roughness, investigated by atomic force microscopy (AFM) corroborates the high quality, while the TTV is monitored by capacitive scanning and Fourier transform Infrared (FT-IR) measurements. The remaining SSD level after FA CMP is investigated by oxide induced stacking fault (OISF) method and results are used to adjust for minimal final polishing of the substrates. Influence of the process parameters on the results is elucidated. The overall process sequence is highly advantageous in terms of performance in TTV and provides a highly competitive and effective method for achieving best possible surface quality with minimized total silicon removal, not only being useful for SOI but also for other areas of silicon processing.

9:45 AM W3.5
The Effect of Pad Conditioning on Planarization Characteristics of Chemical Mechanical Polishing (CMP) with Ceria Slurry. Yuichi Yamamoto[1], Takaaki Kozuki[1], Shunichi Shibuki[1], Keiichi Maeda[1], Yasuaki Inoue[2], Shinji Tawara[2] and Naoki Toge[2]; [1]Semiconductor Technology Development Group., Sony Corporation, Atsugi, Kanagawa, Japan; [2]Technical Dept., Noritake Super Abrasive Ltd., Ukiha-gun, Fukuoka, Japan.

For the 65nm process and beyond, the chemical mechanical polishing (CMP) process using ceria slurry is indispensable for SiO2 planarization. On the other hand, an in-situ dressing is an important technique to achieve a higher throughput and a higher stability. However, the combination of the ceria slurry and the in-situ dressing was resulted in degrading planarization characteristics and a corrosion of the dresser in our trial. It is a new problem that has never occurred in the CMP process using silica slurry. Due to the process consideration, the in-situ dressing is applied in a higher rotation speed of the polishing pad and in an acidity condition of the ceria slurry. We assumed that the degradation of the planarity is caused by high cut rate of the polishing pad and the corrosion is inevitable in the case of dresser with electroplated Ni layer. Therefore, we have developed a new Single Layered Metal Bonded Dresser. The new dresser was able to reduce the pad cut rate to 1/5 of the original rate. The characteristic of the new dresser has substantially strong fixation of the abrasive. We applied this dresser to CMP process using both ceria slurry and in-situ dressing, and successfully achieved the same excellent planarization characteristics as that using ex-situ dressing. The dresser also showed a good corrosion resistance in the ceria slurry. We set up a hypothesis as a reason for the degradation of planarization characteristics that the degraded surface morphology made by over-dressing caused a softening of the pad surface, and surfactants in the slurry, which works as a suppressor of polishing, was not removed enough from the convex portion of the wafer surface. This hypothesis was proved experimentally.

SESSION W4: CMP of Dieletrics
Chair: A. Philipossian
Wednesday Morning, March 30, 2005
Room 2024 (Moscone West)

10:30 AM *W4.1
Studies on Damage due to CMP during Integration of Porous low K Materials. Sharath Hosali[1] and Eric Busch[2]; [1]SEMATECH, Austin, Texas; [2]SEMATECH / AMD, Austin, Texas.

In order to meet the targets for the inter-metal dielectric constant, as required by the ITRS roadmap, porous materials will need to be introduced into the interconnect scheme at the 45nm node and below. The porous nature of these dielectrics result in severe challenges to all unit processes. The porosity and weak mechanical strength of the current generation of ultra low K materials pose significant issue in CMP of even two metal layers. Along with the traditional metrics used for CMP such as dishing, erosion, metal / dielectric loss, additional outputs such as stack integrity or delamination, cap thickness control and retention and low K damage also need to be monitored and controlled. We have examined the various factors affecting these new outputs. We found that many factors, including material properties, pre and post treatments for hard-masks and etch stop layers, deposition thicknesses, design layouts, CMP process aggressiveness, and consumable characteristics, all play a role in controlling delamination. Various failure modes, some of which are new modes that show up only upon electrical testing, are categorized. We present some possible solutions to avoid these failures and the limitations of these solutions. In efforts to optimize for effective K, the effect of CMP stop layer thinning and removal are investigated, and we have determined the effects of moisture absorption and structural modification during direct CMP of low K. Examples of CMP process sensitivity of RC products of one level single damascene and two level dual damascene structures are presented.

11:00 AM W4.2
Correlation of Defects on Dielectric Surfaces with Large Particle Counts in Chemical-Mechanical Planarization (CMP) Slurries Using a New Single Particle Optical Sensing (SPOS) Technique. Edward E. Remsen, Sriram P. Anjur, David Boldridge, Mungai Kamiti and Shoutian Li; Cabot Microelectronics Corporation, Aurora, Illinois.

The critical requirement for defect-free polishing and planarization of dielectric surfaces during the production of microelectronic devices places extraordinary demands on the quality and purity of chemical-mechanical polishing (CMP) slurries used for this purpose. A CMP slurry optimized for defect-free polishing typically exhibits a well-controlled size distribution of its abrasive component, for example, fumed silica. Manufacturing procedures employed in CMP slurry production reach this level of polishing performance by limiting the inclusion of large abrasive particles, nominally greater than 0.5 microns in diameter, in commercial materials. This practice is based on the current paradigm of defect generation during CMP which attributes defect creation to the abrasive action of the largest-sized particle populations of the CMP slurry. A variety of characterization methods have been applied to validate this correlation between defect number and CMP slurry particle properties. Light scattering methods, particularly, single particle optical sensing (SPOS), are widely practiced to evaluate the large particle count (LPC) in CMP slurries and to establish correlations between defect number and slurry LPC. In this paper modifications to the SPOS method that enhance its capability for this application are described. Model studies with fumed silica CMP slurries are used to illustrate the development of a correlation between slurry LPC and defects generated on dielectric surfaces during CMP on a table-top polisher.

11:15 AM W4.3
Chemical Mechanical Planarization Challenges in Integration of Low Dielectric Constant Materials.
Parshuram Bakrishna Zantye[1,2], Ashok Kumar[1,2] and Arun Kumar[2]; [1]Department of Mechanical Engineering, University of South Florida, Tampa, Florida; [2]Nanomaterials and Nanomanufacturing Research Center, University of South Florida, Tampa, Florida.

Chemical Mechanical Planarization (CMP) is increasingly becoming the process of choice to planarize the constituent layers of the Multilevel Metallization (MLM) structures used in Integrated Circuit (IC) interconnects. The different thin films that constitute a given dual damascene structure of a MLM metallization scheme have largely peculiar integration issues. Due to the inherent soft and weak nature of low dielectric constant (low k) and ultra low k materials, CMP of these materials poses numerous challenges. The low k materials are excessively prone to several CMP process defects such as microscratches, delamination, dishing etc., under the compressive and shear forces during CMP. In this research, we have performed chemical mechanical polishing of benzocyclobutene (BCB) polymeric interlayer dielectric (ILD) cured at different temperatures. The mechanical, tribological and interfacial properties are evaluated. A soft CMP pad is chosen for planarization experiments. Novel slurry containing polymeric particles that match the hardness of the polished layers is developed for application specific polishing purposes. The variation of coefficient of friction (COF), acoustic emission (AE) and process end point is detected in situ on the CETR Bench Top CMP tester used for polishing. Other CMP process output parameters such as surface roughness, removal rate, planarization efficiency, defectivity are studied using off line metrology techniques. The softer pad and application specific slurry particles have shown a significant decrease in the process defectivity, without compromising on other process out put variables.

11:30 AM W4.4
CMP Compatibility of Partially Cured Benzocyclobutene (BCB) for a Via-First 3D IC Process. J. J. McMahon, F. Niklaus, R. J. Kumar, J. Yu, J. -Q. Lu and R. J. Gutmann; Focus Center - New York, Rensselaer: Interconnections for Hyperintegration, Rensselaer Polytechnic Institute, Troy, New York.

Wafer-level three dimensional (3D) IC technology offers the promise of decreasing RC delays by reducing long interconnect lines in high performance ICs. This paper focuses on a via-first 3D IC platform, which utilizes a back-end-of-line (BEOL) compatible damascene-patterned layer of copper and Benzocyclobutene (BCB). This damascene-patterned copper/BCB serves as a redistribution layer between two fully fabricated sets of ICs and, ideally, offers high bonding strength as well as low contact resistance for flexible inter-wafer interconnects between the wafer pair. The process combines the electrical advantages of 3D integration technology using copper-to-copper bonding with the mechanical advantages of 3D integration technology employing BCB-to-BCB bonding. However, the planarity of the damascene-patterned copper/BCB needs to be well controlled in order to facilitate such a 3D integration process employing simultaneous bonding between BCB-to-BCB, copper-to-copper, and BCB-to-copper interfaces. In this work, partially cured BCB has been evaluated for copper damascene patterning using commercially available CMP slurries as a key process step for a via-first 3D process flow. BCB is spin-cast and cured on 200 mm wafers at temperatures ranging from 170°C to 250°C, providing a wide range of crosslink percentage. These films are evaluated for CMP removal rate, selectivity to copper and tantalum, surface damage (surface scratching and embedded abrasives), and planarity with commercially available copper CMP slurries under various process parameters. Dishing, erosion, and roughness changes will be presented for single-level damascene test patterns. After wafers are bonded under controlled temperature and pressure, the bonding interface is inspected optically using glass-to-silicon bonded wafers, and the bond strength is evaluated qualitatively by a razor blade test.

11:45 AM W4.5

Effect of CMP Solution Chemistries on the Accelerated Crack Growth of Nanoporous Low-k Thin-Films. Eric P. Guyer and Reinhold H. Dauskardt; Materials Science & Engineering, Stanford University, Stanford, California.

Considerable research efforts have been directed at integrating nanoporous ultra-low dielectric constant nanoporous materials into the interconnect structures of high-density integrated circuits. The reliable fabrication of devices containing these extremely fragile materials is, however, a significant technological challenge due to their high propensity for mechanical failure during all levels of processing and subsequent device packaging in which they are subjected to mechanical loads in the presence of chemically active environments. In this presentation, we demonstrate the significant effect of solution pH on increasing the rate of crack growth in nanoporous methylsilsesquioxane (MSSQ) thin-films. In general, acidic solutions inhibit crack growth and basic solutions accelerate cracking. However, anomalously high crack growth rates were observed in weakly acidic hydrogen peroxide solutions, where at significantly reduced applied loads crack growth rates were accelerated some three orders of magnitude beyond those expected for equivalent pH solutions. We also report the effect of both acidic and basic commercially available post CMP cleaning solutions. Here, the acidic solutions are demonstrated to be just as potent as the basic solutions and growth rates are $\sim$2 orders of magnitude more than those expected based on the pH of the solution. We elucidate the chemical interactions and molecular mechanisms responsible for the accelerated cracking in terms of a stress enhanced chemical reaction between strained crack tip bonds and environmental species. Implications for the integration of nanoporous thin-films into emerging device technologies are considered.

SESSION W5: CMP Modeling and Simulation
Chairs: David Evans and Mansour Moinpour
Wednesday Afternoon, March 30, 2005
Room 2024 (Moscone West)

1:30 PM *W5.1

CMP at the Wafer Edge – Modeling the Interaction Between Wafer Edge Geometry and Polish Performance. Duane S. Boning and Xiaolin Xie; Microsystems Technology Laboratories, MIT, Cambridge, Massachusetts.

As the drive to improve integrated circuit manufacturing yield continues, renewed attention is being paid to the edge of the wafer. The industry is seeking to reduce the edge exclusion region and achieve good performance to within 2 mm or smaller. This creates substantial challenges, both for CMP and for the starting wafer. In this work, we consider two key elements that play a role in nonuniform polish near the edge of the wafer. First, we study the impact of localized pressure on the edge of the wafer as a function of the wafer and retaining ring pressures, gap separation between wafer and retaining ring, and pad material properties (pad Young's modulus). Simulations show that several millimeters into the wafer from the edge can polish either more quickly or more slowly than the center of the wafer, depending on the combination of these parameters. Second, we also consider the impact of wafer edge roll-off (the specific thickness or front surface elevation of the wafer geometry) on polishing uniformity. We again find that the polish uniformity can be affected dramatically, depending on the details of the starting wafer geometry. We believe that several innovations and optimizations are likely to arise in order to meet future wafer edge polish uniformity requirements. These include tool geometry and process improvements, tailoring of the pad material properties, and starting wafer edge geometry optimization and control.

2:00 PM W5.2

Yield Improvement via Minimization of Step Height Non-Uniformity in Chemical Mechanical Planarization (CMP). Muthukkumar Kadavasal[2], Sutee Eamkajornsiri[3], Abhijit Chandra[2,1] and Ashraf Bastawros[1,2]; [1]Aerospace Engineering, Iowa State University, Ames, Iowa; [2]Mechanical Engineering, Iowa State University, Ames, Iowa; [3]Industrial and Manufacturing Systems Engineering, Iowa State University, Ames, Iowa.

Obtaining local and global planarity is one of the prime criteria in dielectric and metal planarizations. Although Chemical Mechanical Planarization (CMP) helps us achieve this criterion in constant pattern density surfaces, the same does not happen with variable pattern density surfaces, resulting in formation of global step heights across the die. This paper provides a controlled open loop algorithm to obtain planarity across a pattern dependant die with pressure and velocity as constraints. Based on the variation of pattern density and surface heights across the die, the surfaces are separated into zones and the pressure and velocities are varied spatially individually and together, to obtain uniform surface heights, with enhanced step height uniformity. The final surface predictions have improved uniformity on the upper surface as well as on the step heights across the entire die. The simulation would help us control the polishing process, in die scale, resulting in a uniform final surface evolution, on a die surface that has variable pattern densities.

2:15 PM W5.3

A Predictive Model for Controlling Wafer Level Polish Rate Uniformity in Oxide CMP. Tushar Merchant[1], Suman Banerjee[1], Leonard J. Borucki[1,2], Andrew S. Lawing[1,3] and John N. Zabasajja[1]; [1]Technology Solutions, Freescale Semiconductor, Tempe, Arizona; [2]Intelligent Planar, Mesa, Arizona; [3]Rohm and Haas Electronic Materials, Phoenix, Arizona.

Chemical Mechanical Polishing (CMP) has become the mainstay of planarizing material layers needed to meet the lithographic requirements at current technological nodes. With the increasing requirements of within wafer uniformity range at each technological node combined with the limited options available to the process engineer to adjust the process, it becomes extremely time consuming and expensive to tweak processes for optimal performance. Historically also, CMP processes have been plagued by variations in consumable quality. This problem manifests itself as inconsistent polish performance, both in terms of the quality of the outgoing product and limited consumable lifetime. One continuing problem is the constant adjustment of tool settings to maintain a desired polish rate profile through the edge of the wafer, based on the incoming wafer thickness, the particular mask layout as well as the current age of the consumable set. There have been a number of mechanical stress based models that have looked at prediction of wafer level polish rates for oxide polishing and show qualitative match to the data, however none have been successful in getting a quantitative match to actual tool settings. We have developed a stress based engineering model that predicts the removal rate across the wafer as a function of the principal and shear stresses on the wafer. The principal stresses are the result of wafer bending due to the applied down force and when the wafer surface is under tension, the bending terms increase the removal rate while under compression they decrease it. By adjusting the pressure distribution on the back of the wafer and the edge torque it is possible to adjust the wafer level polish profiles as is nominally accomplished in various CMP tools. This model has been used to predict the effect of the backside air pressure in an IPEC-472 CMP tool on wafer level polish profiles. The model reproduces the form of the radial variation in polish rate that is seen without back side air for the current set of consumable conditions and the changes in the polish rate profile that occur when back side air pressure is used. The model which is GUI based and can be run in the fab, returns the optimum recipe setting to maximize polish rate uniformity based on the current tool performance. The same model has also been extended to the AMAT Mirra platform, where the effect of retaining ring pressure on wafer level polish profiles is predicted for different conditions. Implementing this model in production resulted in a 50% improvement in within wafer uniformity statistics.

2:30 PM W5.4

Quantitative In-Situ Measurement of Asperity Bending Under the Wafer During CMP. Caprice Gray[1], Daniel Apone[1], Vincent Manno[1], Chris Barns[3], Mansour Moinpour[2], Sriram Anjur[4] and Chris Rogers[1]; [1]Mechanical Engineering, Tufts University, Medford, Massachusetts; [2]Intel Corporation, Santa Clara, California; [3]Intel Corporation, Hillsboro, Oregon; [4]Cabot Microelectronics, Aurora, Illinois.

The interaction of the wafer, slurry and pad determines the material removal rate during Chemical Mechanical Planarization (CMP). Dual emission laser induced fluorescence (DELIF) provides a means to observe the slurry layer between the wafer and pad in-situ during CMP with high spatial and temporal resolution. We used DELIF to study the fluid layers between a glass wafer and a Fruedenberg FX9 pad during CMP. In-situ images are taken at a frequency of 2 Hz over an area of 1.6mm x 2.7mm. Optical BK7 glass wafers were etched such that they contained multiple square wells. The image analysis indicates that slurry conforms to both pad asperities and wafer topography. Asperity compression inside and outside these wells can be deduced based upon ex-situ surface roughness measurements. Asperity regions under 14um deep wells have the have a similar surface roughness, 4.6+/-0.4um, to a dry pad measured with a profilometer, 4.9+/-0.3um. However, the surface roughness under the unpatterned region of the wafer is only 3.8+/-0.3um, suggesting asperity compression of 1.6+/-0.4um during polishing.

2:45 PM W5.5
A Dishing Model for STI CMP Process. Shih-Hsiang Chang, Department of Mechanical Engineering, Far East College, Tainan, Taiwan.

As a result of the steady shrink of device geometry and channel length, shallow trench isolation (STI) is needed to offer near zero field encroachment, better planarity, latch-up immunity, and low junction capacitance compared with the traditional local oxidation of silicon (LOCOS) isolation technique. However, oxide dishing occurred in STI CMP will expose the side of active area and lead to considerable sidewall and edge-parasitic conduction as well as high electric fields in the gate oxide at the active-area edge, thereby reducing the field threshold voltage. It is therefore essential to understand its dependence on pattern geometry and polishing process parameters. Based on the assumption of direct pad-wafer contact, the processes of STI CMP can be modeled as 3D elastic periodic wear-contact problems. For sufficiently long polishing time, the steady-state oxide dishing can be calculated as the difference of surface displacement between the center and the edge. It is clearly seen from the variation of the oxide dishing with pattern density at fixed pitch for an IC1400 pad that dishing increases with increasing pattern density up to a certain value beyond which it decreases dramatically. Similar result has been observed by Park et al. and predicted by Chang in Cu CMP. Further, the location where the maximum value of dishing occurs moves toward higher pattern density as the pitch decreases. These phenomena should be considered in IC circuit design. The effect of the pattern density on the oxide dishing at fixed trench width shows that he slope of the curves in dishing appears to be very small as the pattern density is varied in the range between 30% and 70%. This indicates that the value of dishing is insensitive to the pattern density in this range. However, such insensitivity tends to disappear at larger trench widths. Outside this range, the dishing is seen to increase dramatically as the pattern density increases. Another important result is that oxide dishing strongly depends on trench width, but minimally on pattern density. This is consistent with experimental observation by Yu et al. and Chen et al.. A physics-based dishing model that can quantitatively predict the effect of process parameter on oxide dishing occurred in CMP of STI structures has been developed. Although the dishing model presented focus on steady-state regime and is based on a periodic structures, it correctly predicts not only about the same magnitude for oxide dishing as that measured experimentally but also the effect of process parameters on oxide dishing. Thus, it is expected that this model could provide basic design rules in optimizing process parameters and pattern geometry for STI, thereby reducing the time and cost required to develop new metallization architecture for sub-micron devices.

3:15 PM *W5.6
Optimal CMP Processing Utilizing Through-the-Pad Slurry Delivery. Thomas Laursen, Novellus Systems, Chandler, Arizona.

The orbital polishing platform constitutes the basis for one category of high-productivity CMP tools, which are designed to meet the stringent wafer metrics of 65-nm technology node and beyond. The most apparent characteristic of these tools is their confined orbital motion (1.25" orbit diameter) between wafer and pad. This characteristic is responsible for the compact polish-module design, where the polish-pad diameter exceeds the wafer diameter by only 4". This design feature has lead to very efficient pad utilization. Another, but less conspicuous, aspect of this design is the through-the-pad slurry delivery (TPSD), which together with the orbital motion controls slurry distribution between wafer and pad. The slurry delivery and distribution and their impact on process performance and cost-of-ownership will be the topic of this presentation. TPSD has been accomplished by the fact that most of the pad is exposed to the wafer at all times. Forced slurry delivery to the pad-wafer interface prevents slurry starvation and enables uniform polish profiles to be obtained for a wide range of process conditions. Two aspects of the slurry delivery will be discussed in detail. The first is with regard to slurry consumption. Several processes have been developed for the 200-mm and 300-mm platforms, where slurry consumption is very low. This will be illustrated by the Hitachi T805 barrier process, where slurry cost per 300-mm wafer was reduced from $6 to less than $2 with little or no impact on polish uniformity and defectivity. The other aspect relates to the slurry distribution providing a low threshold for polish initiation at low pressures for certain slurries and chemistries such as Eternal 2362 and Hitachi C430. In the case of abrasive-free polish with C430 at 2 Psi, where initiation times on the rotational platform exceeds two minutes, a relatively short initiation of 20 s were measured on the orbital platform. It has also been shown that after initiation, the Prestonian relation is similar for the two platforms. It is expected that this unique slurry-delivery design can provide extendibility of the orbital polisher beyond the 65-nm node. The presentation will finish by discussing on-going work on optimization of slurry-delivery locations and pad-grooving design. Further improvements are expected by adopting a two- or three-zone delivery system. In both cases the development is expected to benefit greatly from modeling. Computational fluid dynamics modeling has already led to the use of an improved pad-grooving concept for our processes of record.

3:45 PM *W5.7
On the Relationship of CMP Wafer Nanotopography to Groove-Scale Slurry Transport. Gregory P. Muldowney, Advanced Research Group, Rohm and Haas Electronic Materials CMP Technologies, Newark, Delaware.

Material removal in CMP occurs during intervals of pad-wafer contact separated by intervals of non-contact. One predictable sequence of non-contact intervals for a fixed point on the wafer is the traverse of the pad grooves, during which the wafer surface is renewed with fresh chemistry and heat is conveyed away. It is well understood that good uniformity requires machine kinematics that expose all points on the wafer to the same total contact time, mean slurry concentration, and temperature. Less widely known is that coherent structures tens to hundreds of nanometers high and matching the pitch of the pad groove pattern may be formed on an otherwise planar wafer despite multiple rotary motions. This unexpected phenomena is of interest not only because it manifests the impact of grooves and transport at scales not easily studied, but also because shrinking device architectures will ultimately disqualify even nano-scale departures from planarity. Computational 3-D model results are presented for slurry mixing dynamics in the pad-wafer gap of a 200-mm dual-axis polisher alternately using circular, Cartesian grid, and spiral groove patterns. Wafer polish experiments are then conducted with the same groove patterns using specialized pad conditioning and CMP recipes to amplify groove-induced nanotopography. Experimental results illustrate sharp patterns in finished wafers (visible to the naked eye) that should not be possible on a dual-axis tool. A direct correspondence is established between the observed wafer nanotopography and predicted groove-scale slurry mixing dynamics. In particular, the surface structures are underpolished areas traceable to regions of depleted polish chemistry that persist briefly in groove segments when oriented parallel to the pad and wafer rotation directions. The study conclusively defines the features required in a groove pattern and polish recipe to form coherent structures matching the groove pitch. As validation of the theory, a groove pattern expected to form no surface topography is defined, experimentally tested, and shown to perform as predicted. Findings are discussed in the context of next-generation pad grooving and texturing as required for progressively more demanding applications of CMP.

4:15 PM W5.8
Synergy between Chemical Dissolution and Mechanical Abrasion During Chemical Mechanical Polishing of Copper. Wei Che[2], Ashraf Bastawros[1,2] and Abhijit Chandra[2,1]; [1]Aerospace Engineering, Iowa State University, Ames, Iowa; [2]Mechanical Engineering, Iowa State University, Ames, Iowa.

The synergistic role of chemical dissolution and mechanical abrasion on the material removal mechanism during CMP process is explored. A set of nano-wear experiments on electro-plated copper surfaces are conducted with a systematic exposure to active slurry. Initial results of in situ wear test in chemically active slurry showed an increased material removal rate (MRR) relative to a dry wear test. To understand the synergistic effects of chemical dissolution and mechanical abrasion, we have investigated two plausible mechanisms of material removal. Mechanism-I is based on chemical dissolution enhances mechanical abrasion. A soft layer of chemical products is assumed to be formed on top of the polished surface due to chemical reaction with a rate much faster than the mechanical abrasion rate. It is then followed by a gentle mechanical abrasion of that soft layer. It is found that, for pure copper etched with ammonium hydroxide, the yield strength of film is about 50% of the substrate yield strength; the modulus of film is about 20% of the substrate modulus. The film thickness is found to be in the order of few nanometers, and increases with the etching time according to first order linear kinetics. Mechanism-II is based on mechanical abrasion accelerating chemical etching. In this case, the nano-wear experiment is first performed to generate local variation of the residual stress levels, and then followed by chemical etching to investigate the variation of the wear depth and the evolution of surface topography due to etching. It is found that the residual stress caused by the mechanical wear enhances the chemical etching rate, as manifested by the increase of wear depth. The developed understanding from these experiments can be used in future studies to control the rates of chemical dissolution and mechanical abrasion as well as investigating the various process-induced defects.

4:30 PM W5.9

Modeling of Polishing Regimes in Chemical Mechanical Polishing. Suresh B. Yeruva[1,3], Chang-Won Park[2,3] and Brij M. Moudgil[1,3]; [1]Department of Materials Science and Engineering, University of Florida, Gainesville, Florida; [2]Department of Chemical Engineering, University of Florida, Gainesville, Florida; [3]Particle Engineering Research Center, University of Florida, Gainesville, Florida.

Chemical mechanical polishing (CMP) is widely adopted in producing excellent local and global planarization for microelectronic device manufacturing. It has been demonstrated experimentally that the polishing performance is a result of the synergistic effect of both the chemicals and the particles involved in CMP. However, the fundamental mechanisms of material removal and the interactions of the chemical and mechanical effects are not well understood. A comprehensive model for CMP was developed taking into account both the chemical and mechanical effects for monodisperse slurries. The chemical aspect is attributed to the chemical modification of the surface layer due to slurry chemistry, whereas the mechanical aspect is introduced by indentation of particles into the modified layer and the substrate depending on the operating conditions. In this study, the model is extended to include the particle size distribution effects. The refined model not only predicts the overall removal rate but also the surface roughness of the polished wafer, which is an important factor in CMP. The predictions of the model show good agreement with the experimental observations in many aspects.

4:45 PM W5.10

Modeling Pattern Effects in Oxide CMP. Roland Rzehak, Infineon Technologies SC300 GmbH & Co. OHG, Dresden, Germany.

We present an extension of the density-stepheight model [1] for pattern effects in oxide CMP. The model is compared to polishing data for processes using different pressure and speed. Agreement with the data is improved especially in the initial regime of polishing before the pad contacts the down areas. Implications for process optimization are discussed. [1] D.O.Ouma et al IEEE Trans. Semiconductor Manufacturing 15 (2002) pp 232.

SESSION W6: Poster Session: Chemical-Mechanical Planarization - Integration, Technology and Reliability

Chairs: Earl C. Johns, Ashok Kumar, Jeffrey Lee, Yaw Obeng and Ingrid Vos
Wednesday Evening, March 30, 2005
8:00 PM
Salons 8-15 (Marriott)

W6.1

Abstract Withdrawn

W6.2

Frictional Behavior and Particle Adhesion of Abrasive Particles during Cu CMP. Yi Koan Hong, Dae-Hong Eom, Ja-Hyung Han, Jae-Hoon Song and Jin-Goo Park; Division of Materials and Chemical Engineering, Hanyang University, Ansan, Kyung-Ki Do, South Korea.

The friction behavior and adhesion of alumina and silica abrasive particles were theoretically and experimentally investigated during Cu CMP process. The adhesion force of particles on surface was measured using an Atomic Force Microscope (AFM, Park Scientific Instruments CP Research) by directly measuring the force required to remove them from a surface. A spherical alumina (40μm in diameter Micron Co., Japan) and silica (40μm in diameter, Duke Scientific Co.) particle were attached on a tipless cantilever. The adhesion force was measured between particle and wafer surfaces in a liquid cell. Frictional behavior of alumina and silica abrasive particles were measured using a polisher which could measure the friction force in-situ. Electroplated Cu wafer and Cu disc were used for the adhesion force measurement and the polishing experiments, respectively. Cu wafers were pre-cleaned in diluted HF (DHF, 0.01 vol%) solution and DI water for 1 min and 30 sec, respectively. The frictional and adhesion forces between the particles and wafer surfaces were experimentally measured using alumina and silica slurries with and without citric acid, respectively. The highest particle adhesion force was measured in alumina slurry without citric acid. However, the alumina slurry with addition of citric acid had the lowest particle adhesion due to the adsorption of citrate ions on the alumina surfaces. While citrate ions could be easily adsorbed on alumina particles, silica particle showed the least effect on adsorption in citric acid solutions. The magnitude of adsorptions of citrate ions on the particle surfaces had significant effect on frictional behavior as well as adhesion force. Higher particle adhesion force generated higher friction between the particle and surfaces during CMP process. It indicates that the magnitudes of particle adhesions on wafer surfaces in slurries can be directly related to the frictional behavior during CMP process. The interaction forces between the particle and wafer surfaces during Cu CMP were also calculated based on the Derjaguin-Landau-Verwey-Overbeek (DLVO) theory on the different abrasive particles.

W6.3

Study on the Planarization Behaviour of Copper CMP Utilizing Dense Pattern and a Global Step. Tilo Bormann[1,2] and Johann W. Bartha[2]; [1]IFD MDC UPD FP, Infineon Technologies Dresden GmbH & Co. OHG, Dresden, Germany; [2]Institute of Semiconductor and Microsystems Technology, Dresden University of Technology, Dresden, Germany.

The major aim of CMP is not the removal of excess material but the planarization of the surface. Therefore the determination of the planarization length appears to be more important than the removal rate itself. It has been shown, that the planarization length is not a constant process parameter, but is related to the removal respectively to the polish time in a square root behaviour. Founded on models proposed by Boning, Ouma, et. al. we applied a sequential polish on a single quasi infinite step. The resulting profile could be simulated by a sequential convolution of the surface contour with a Gaussian transfer function. To come closer to the situation on a chip pattern we investigated the planarization behaviour on a specific pattern of the MIT854AZ copper CMP test chip, where a large area of unpatterned surface touches a pattern with a specific constant density. The 200 mm wafer samples consisted of RIE structured oxide films covered with 850 nm ECD copper. The polish was performed on a standard semiconductor manufacturing tool, using a commercial consumables set. The surface profiles were determined by a high resolution profiler for an entire polishing sequence. The densely patterned areas are removed within a specific polishing time while the transition point between the unpatterned and patterned area appears as a single global step. The deposited copper thickness is sufficient to study the contour evolution in both phases, before and after removal of the pattern. It turned out, that the contour evolution in the densely pattern area before it is removal could not be described and simulated by a convolution with a simple Gaussian transfer function, which however yields good results for the evolution of the single global step. The paper will present the experimental results on the contour evolution for different density fields and discuss different approaches for a determination of transfer functions appropriate for the patterned fields as well as the global step.

W6.4

Effect of Organic Modification of Nano Sized Silica Particles on the Surface Roughness of Copper Film in Cu CMP Process. Sangkyu Lee[1], Sang-Kyun Kim[1], Jung-A Choi[1], Kyung-Hoon Hyun[1], Ungyu Paik[1], Takeo Katoh[2] and Jea-Gun Park[2]; [1]Ceramic Engineering, Hanyang University, Seoul, South Korea; [2]Nano SOI Laboratory, Hanyang University, Seoul, South Korea.

The surface roughness of copper film was investigated with nano sized organically modified silicates (ORMOSILs) in Cu chemical mechanical planarization (CMP). The ORMOSILs were synthesized using methyltrimethoxysilane (MTMS) as a precursor, and the physical characteristics of the particles were controlled by mixing ratio of the precursor and the solvent. In order to identify the relationship between the particle characteristics and the CMP performance, the physical properties of the ORMOSILs were analyzed with high resolution TEM image, rate of organic modification, and the particle density. The Cu CMP was evaluated using the silica particle with and without organic modification, and then the polishing performances such as removal rate, within wafer non-uniformity (WIWNU), and surface roughness of polished copper film were characterized. The results showed that Cu CMP slurry with ORMOSILs as abrasives could achieve good surface planarity for Cu CMP.

W6.5

Colloidal Behavior of Alumina Abrasives in Copper CMP Slurries. Robin Veronica Ihnfeldt and Jan B. Talbot; Chemical Engineering, UC San Diego, La Jolla, California.

The influence of common slurry additives on the colloidal behavior of alumina suspensions used for copper CMP were investigated. The alumina suspensions were characterized using zeta potential and particle size distribution measurements with various chemical additives and in the presence of nanometer-sized (<100 nm, from Aldrich) copper particles. The results are compared to the colloidal behavior of the same slurries without the addition of copper. The alumina slurry (from Cabot Corporation) consisted of 40 wt% α-alumina particles (180 nm avg diameter) in de-ionized water. Samples for testing were diluted to 0.1 wt% alumina using a 1mM KNO_3 solution. The zeta potential and particle size were measured as the pH of the solution was altered from 2 to 12. The concentration of copper in slurry during CMP was calculated to be 1.6 mM assuming a removal rate of 100 nm/min for a slurry flow rate of 150 ml/min on a 150 mm wafer. Therefore, the concentration of copper in the samples was 0.12 mM, so that the ratio of copper and alumina was similar to that during CMP. The particle size of copper could not be measured at this low concentration of 0.12 mM. Therefore, the particle size measurements are only of the alumina. Typical alumina particle sizes without any additives, including copper, were 200-400 nm at pH values <5, and ~1 μm at pH values >7. The addition of copper caused an increase in the alumina particle size ranging from 300-1000 nm at pH values >7. This is most likely due to the oppositely charged copper (IEP ~9) adsorbing onto the alumina (measured IEP ~7), thereby increasing the effective particle size. The addition of glycine, a stabilizing agent, eliminated the interactions between alumina and copper by increasing the IEP of the alumina to ~9. The addition of 0.1 wt% H_2O_2 to the slurry did not have any effect on the particle size without copper, but increased the particle size to ~2 μm for all pH values with copper. This is due to a 10 ($\pm$3) mV decrease in the zeta potential for all pH values with copper addition. Increasing the concentration of H_2O_2 to 2.0 wt%, both with and without copper, caused the alumina particle size to decrease to that typically observed without additives. The anionic surfactant, sodium-dodecyl-sulfate (SDS), caused the zeta potential to become negative (-5 to -20 mV) for all pH values with and without copper. Benzotiazole (BTA), a corrosion inhibitor, had no effect on the particle size. The combination of the slurry additives (0.1M glycine, 0.1 wt% H_2O_2, 1mM SDS, and 0.1 wt% BTA) without copper caused the zeta potential to remain ~0 ($\pm$7) mV and the alumina particles to agglomerate (>3 μm) for all pH values. Addition of copper into this mixture had no effect on the zeta potential (~0 mV), but the alumina particle size decreased to that typically seen without additives. This data shows the alumina dispersion is significantly affected by both the chemical additives and the addition of copper into the solution.

W6.6

A Study of the Effect of Slurry Temperature on Cu Chemical Mechanical Polishing (CMP) with H2O2 and KIO3 as Oxidizing Agents. S. Mudhivarthi[1,2], Parshuram Bakrishna Zantye[1,2], Arun Kumar[2] and Ashok Kumar[1,2]; [1]Department of Mechanical Engineering, University of South Florida, Tampa, Florida; [2]Nanomaterials and Nanomanufacturing Research Center, University of South Florida, Tampa, Florida.

Chemical Mechanical Planarization (CMP) has evolved as one of the most critical and significant process in semiconductor manufacturing. Cu has replaced Al for metallic interconnects in the integrated circuit as the former has much lower resistivity. One of the major factors that affect the planarization process is the pad-wafer interface temperature. This factor has been researched to a relatively lesser extent. The chemical aspect of the removal process during Cu CMP is sensitive to subtle temperature changes at the interface. In this research, the variation of the electrochemical behavior of two most commonly used oxidizing agents, H2O2 and KIO3, with a change in temperature has been studied. Potentiodynamic tests have been conducted at various temperatures for the commercial slurry containing the aforementioned oxidizing agents using a potentiostat. A three electrode configuration has been used with thin rectangular copper wafer piece as the working electrode, platinum wire as the counter electrode and Ag/AgCl electrode as the reference electrode. A potential sweep of -0.9 to 0.9 V has been applied to the working electrode and the resulting current output has been measured. For the given potential range the variation of the output current has been plotted to estimate the corrosion potential and corrosion current. Further, the open circuit potential variation with temperature for both the slurry systems has been estimated. The main objective of this research is to understand the electrochemical behavior of the two most commonly used oxidizing agents for Cu CMP and their sensitivity to temperature.

W6.7

Pattern Symmetry and CMP Process Simulation. Takafumi Yoshida, Dept of TCAD, YNT-jp.com, Hikari, Yamaguchi, Japan.

This paper reviews the effect of pattern symmetry on Chemical Mechanical Planarization (CMP) and proposes a methodology to reduce the computational time of CMP process simulation based on boundary element method (BEM). We focus on a unit field which generates the symmetry structures and formulate the BEM field matrix by parallel translations and spin/flip operations. We also discuss the characteristics of the field matrix and demonstrate the applications of the methodology.

W6.8

The Transient and Size Effects of Nanoparticles in Chemical Mechanical Polishing. Taofang Zeng, North Carolina State University, Raleigh, North Carolina.

When a workpiece to be polished is placed on the carrier of a polishing machine, it is pressed down to the polishing pad. Large abrasives make contact between the pad and the workpiece before the smaller ones. The larger abrasives are pressed into the pad and indented into the workpiece. These particles are the active abrasives and participate in material removal. The abrasives with a size less than the gap between the pad and the workpiece move freely in the valleys/voids of the pad, and are inactive. As the gap decreases during the polishing process, smaller abrasives trapped between the pad and the workpiece become active in polishing. Thus the process of chemical mechanical polishing is dynamic. However, all previous modeling is static. This study establishes a dynamic model for the abrasives. The modeling considers the transient motion of the workpiece/particle/pad in the vertical direction, and the change of the roughness of the workpiece. Study of the transient motion shows an increasing number of active particles and a changing polishing rate in the first two minutes. It also demonstrates that the viscoelastic properties of the pad and the workpiece surface roughness are important factors in determining the polishing rate. The study also shows that when the average particle size is smaller than an optimum size, the polishing rate increases with increasing particle size. Yet if the average particle size is larger than the optimum size, the polishing rate decreases with increasing particle size

W6.9

Polishing Slurries with Aluminate-modified Colloidal Silica Abrasive. Irina Belov, Paula Bell, Martin Perry, Joo-Yun Kim, Neal Golovin and Keith Pierce; Praxair Electronics, Indianapolis, Indiana.

Acidic Copper CMP slurries have been developed with low content of colloidal silica abrasive; the sluries provide high removal rates (RRs)and superior stability. Drastic improvement in colloid stability has been achieved by using SiO2 particles with increased negative surface charge through doping /modification with metallate ions Me(OH)4 (-I), particularly with aluminate ions. Copper CMP can be performed in acidic, neutral or alkaline media. Advantages of using a slurry with acidic pH are high RRs and high removal selectivity of Cu compared to Ta/TaN barrier and TEOS dielectrics. Copper slurries typically contain an oxidant, a chelating agent, corrosion inhibitor and abrasive particles, with alumina and silica particles being used the most. Slurries containing amorphous, spherical colloidal silica particles tend to give smooth surfaces with lower defectivity as opposed to fumed silica and alumina containing slurries. The major drawback of colloidal SiO2-based slurries is the reduced RRs. Increase in the RR can be achieved through using a more aggressive chemical package, i.e. lower pH, higher concentration of removal accelerators. Using more aggressive chemistries is also consistent with current trends in developing copper CMP process: a reduction of polishing downforce and using low-abrasive slurries with less than 1- 2 w. % content of abrasive particles. However decreasing slurry pH leads to reduced surface charge and hence destabilization of colloidal SiO2 particles. Also increasing the ionic strength causes the slurry destabilization. As demonstrated by Zeta potential ξ measurements of Cu CMP slurries formulated with pH in the range from 2.5 to 6.5, for nonmodified silica particles a drastic decrease in surface charge has been observed at pH below 4. Colloidal destabilization at low pH also manifested itself through growth of oversized particles. Aluminate-modified colloidal silica particles when incorporated in the same chemical package exhibit significantly larger negative ξ that is practically pH independent in the range of pH=2.5 - 5.0. Stability improvement has been a result of an increase in negative surface charge of colloidal particles because of aluminate ion Al(OH)4 (-I) incorporated into SiO2 surface substituting for Si(OH)4 and creating a fixed negative charge. The developed slurries demonstrated bulk Cu removal rate comparable with typical RRs for alumina- or fumed silica-containing slurries, as well as good planarization efficiency. Thus using aluminate-doped colloidal silica particles in acidic Copper CMP slurries allows to overcome inherent stability limitations and enables production of stable acidic slurries with high RRs while preserving all the morphological advantages of colloidal silica abrasive component. The developed route is also useful for production of acidic polishing slurries for other applications, such as Tungsten and STI CMP, as well as in polishing hard drive disks, fiber optic connectors, etc.

W6.10

Pad Conditioning and Slurry Distribution Evaluation to Improve the Efficiency of Oxide Chemical Mechanical Polishing. Cosimo Patini[1], Andrea Filippini[2], Giulia Monica Spinolo[2] and Maurizio Bacchetta[2]; [1]CMP Technology Group, Applied Material Europe, Caponago, Milano, Italy; [2]Central R&D Agrate, STMicroelectronics, Agrate, Milano, Italy.

In this paper polish rate and related non uniformity are presented over a range of different slurry distribution regime and pad conditioning. In this study we kept constant all Prestonian parameters (pressure and rotational speed), analyzing the impact on both polish rate and non uniformity through different slurry distribution and pad conditioning during only the phase that CMP system spend to reach the steady-state regime. Based on the analysis presented here, a different combination of slurry dispensing and pad conditioning setting during the time CMP system spend to reach the steady-state regime, have a crucial impact on the final on wafers performances. Improvements of both polish and uniformity have been reported by > 30%. The results are consistent with different Prestonian regime. They might be explained by the influence of hydrodynamic slurry and pad surface status prior to reach the steady-state regime.

W6.11

Post CMP Cleaning of Dielectric Surfaces. Henry Liu, Herb Goodman, Brian Santora, David Merricks and Bob Her; Ferro Corp, Penn Yan, New York.

Chemical mechanical planarization (CMP) has decisive advantages over other techniques in achieving global planarization in multilevel circuits with feature size less than 0.5 um. However, due to the use of particles and organics used in CMP formulations used during the CMP processes, submicron abrasive particles tend to adhere to the wafer surface. Post CMP cleaning to remove particles from wafer surfaces is thus a critical process. In this presentation, new cleaning systems were explored in the post CMP cleaning of ceria slurries from oxide surfaces (i.e. STI, ILD). Several parameters were examined including type and amount of surfactants, pH, and addition of chelating agents. The post CMP clean processes were also screened for the effectiveness of particle removal. Post CMP clean defectivity results will be presented using several different post CMP clean formulations under several different conditions.

W6.12

Process of Particle Adhesion and Removal during CMP & Post-CMP Cleaning. Dedy Ng[1], Milind Kulkarni[1], Hong Liang[1], Y. R. Jeng[2] and P. Y. Huang[2]; [1]Mechanical Engineering, Texas A&M University, College Station, Texas; [2]Mechanical Engineering, National Chung Cheng University, Taiwan, Taiwan.

In order to understand particle removal during post-CMP cleaning, we investigate the adhering process of particles toward wafer surface during CMP. The mechanical interaction between abrasive particles and wafer surface was studied using a microcontact wear model. This model considers the particle effects between the polishing interfaces during load balancing. Experiments results are compared with numerical analysis. Our study suggests that during post-CMP cleaing, a combined effort in chemical and mechanical interaction (tribochemical interactions) would be effective in removal small particles during cleaning. For large particles, more mechanical forces would be more effective.

W6.13

Role of Nanoparticle Size and Concentration during Cu CMP. Su-Ho Jung[1] and Rajiv K. Singh[1,2]; [1]Materials Science and Engineering, University of Florida, Gainesville, Florida; [2]Microelectronics Research Center, University of Texas, Austin, Texas.

We have investigated chemical mechanical polishing of copper films using sub 100 nm colloidal silica particles. To understand wafer-particle-pad interactions, an experimental study of removal rate, surface roughness, and in situ friction force as function of particle size and concentration was conducted. With synergistic chemical effects, the removal rate increases with an increase in both particle size and concentration. The surface roughness is not influenced by changes in particle size and concentration and, in all cases, the RMS value is less than 0.7 nm. In situ friction force measurements suggest that the material removal is dominated by an indentation volume-based mechanism.

SESSION W7: CMP Slurries
Chairs: Duane Boning and Mike Oliver
Thursday Morning, March 31, 2005
Room 2024 (Moscone West)

8:30 AM *W7.1

Performance of Silicon, Cerium, and Zirconium Oxide Abrasives in Dielectric CMP. David R. Evans, Sharp Laboratories of America, Camas, Washington.

Although it may appear superficially as a simple process, chemical mechanical polishing of dielectric materials is actually quite complex and depends not only on the chemical activity of the liquid portion of the slurry, but also on the surface chemistry of abrasive particles. In particular, in an aqueous environment, metal oxides actively participate in various pH sensitive adsorption equilibria involving hydrogen and hydroxyl ions. As such, these can be expected not only to affect stability of the slurry suspension as well as particle agglomeration in general, but also elementary interactions between abrasive particles and polished surfaces. Accordingly, even so-called "mechanical removal processes" may in reality have a fundamental chemical nature. In this work, polishing performance of silica, ceria, and zirconia abrasives with respect to removal rate, planarization, and other factors is compared as a function of ambient pH and other relevant process parameters. These results are then correlated with known structural and chemical properties of these abrasive materials.

9:00 AM W7.2

Recent Advances in Ceria Based Slurries for Oxide Polishing. Brian Paul Santora, Bob Her and David Merricks; Ferro Electronic Material Systems, Penn Yan, New York.

New Slurry formulations are described for both Shallow Trench Isolation(STI) and Inner Layer Dielectric (ILD) CMP applications. These formulations use cerium oxide as the abrasive since the industry requires a higher performance from these slurries for both of these applications at sub-90nm technology nodes, compared to the traditionally used silica-based slurries. The slurries for STI CMP show high oxide to nitride selectivity, low dishing and exhibit excellent within wafer (WIW) and within die (WID) performance. The slurries for ILD CMP give very fast step height removal rates. When polishing wafers with a variety of pattern densities and feature sizes, the cerium oxide slurries show lower dependancy on pattern density, as compared to silica slurries. All of the CMP slurries exhibit consistent manufacturability, excellent dispersion characteristics, and long shelf life.

9:15 AM W7.3

Development of an Electrochemical Method - In-Situ Chronoamperometry for CMP Slurry Study. Jian Zhang, Steven Grumbine and Phillip Carter; R&D, Cabot Microelectronics, Aurora, Illinois.

CMP is one of the key processes for semiconductor manufacturing and CMP slurry plays an important role in polishing performance[1]. With the advancement of semiconductor structure, such as copper interconnect, the requirement for CMP slurry related to the performance is at an all time high. Understanding the working mechanism of CMP slurry is critical for future slurry development[2]. In this study, a new electrochemical method – in-situ chronoamperometry (ISCA) has been developed and used as a tool for CMP slurry characterization. The set up of ISCA includes a rotating disk for polishing, stage & base scale for down force control, potentiastate for chronoamperometry measurement. ISCA has been demonstrated in this work to be able to quantify surface reactivity (Y0), surface film robustness (A1) and film forming kinetics (t1). A working example using this technique will be presented and the results will be discussed regarding structure-activity relationship. Reference: 1. Christopher L. Borst, Stanley M. Smith, Mona Eissa, "Challenges and Rewards of Low-Abrasive Copper CMP: Evaluation and Integration for Single-Damascene Cu/Low-k Interconnects for the 90nm Node", K1.1.1 – K1.1.12, Mat. Res. Soc. Symp. Proc. Vol. 816, 2004 Materials Research Society. 2. Melvin K Carter and Robert Small, "Electrochemical Measurements of Passivation Bilayers on Copper in a CMP System", Journal of Electrochemical Society, 151 (10), B563, 2004.

9:30 AM W7.4

Strong Synergistic Effects between Ceria and Montmorillonite Particles in Glass CMP Slurries. Mingming Fang, Michael Ianiro, Don Eisenhour and Jason St. Onge; Amcol International, Inc., Arlington Heights, Illinois.

It has been known in the disk industry that glass substrate has superior shock resistance and higher stiffness for increased rpm and access time than Al/NiP substrate. The main barrier for the desktop computers to use glass instead of Al/NiP has been the high cost of the glass substrate, which mostly caused by its needs of long polishing time. Developing glass CMP slurry that can deliver higher polish rate and less surface defects is a continuous challenge in disk industry. We recently discovered that adding montmorillonite particles into ceria-based glass CMP slurries can significantly increase their polishing rate without sacrificing the surface smoothness. It is the first time to our knowledge that this strong synergistic effect between ceria and montmorillonite particles was reported in the glass CMP area. Several physical properties of the ceria- montmorillonite slurries, such as viscosity, zeta potential, and particle size, are characterized in order to understand the mechanism of the synergistic effect.

9:45 AM W7.5

The Adsorption Behavior of Citric Acid on Colloidal Silica and Alumina Particle in Cu CMP Slurry. Dae-Hong Eom, Jae-Hoon Song, In-Kwon Kim, Jin-Goo Park and Young-Jae Kang; Engineering Bldg 1, Hanyang Uni., Ansan-si, Gyungki-do, South Korea.

The adsorption behavior of citric acid is dependent on the concentration and pH of slurry solution. The maximum amount of citric acid adsorbed on the alumina surface was measured to be 2.17 μmol/m^2 at pH 3. The adsorbed citrates decreased to 1.17 μmol/m^2 at pH 8. The adsorption of citrate causes a highly negatively charged surfaces and the shift of isoelectric point (IEP) to lower pH values. In this study, the absorption effect of citric acid on abrasive particle was evaluated during Cu CMP. The removal rate of Cu in colloidal silica and $\gamma - Al_2O_3$ was strongly dependent on the electrochemical dissolution reaction of Cu at lower concentrations of H_2O_2 than 10 vol%. Although passivation layer was grown on Cu surface at higher concentration of H_2O_2 than 10 vol%, the removal rate drastically increased due to the mechanical abrasion of the passivation layer. The removal rate of Cu in $\gamma - Al_2O_3$ slurry linearly increased with an increase of H_2O_2 concentration even though the dynamic etch rate was slightly decreased at 10 vol% H_2O_2 and pH 4. At acidic pH solutions, the passivation layer was very thin and the removal rate of Cu drastically increased due to the combination of electrochemical reaction and mechanical abrasion at H_2O_2 concentration below 10 vol%. The removal rate of Cu linearly increased as H_2O_2 concentration increased due to the adsorption of citric acid on $\gamma - Al_2O_3$ surface. The removal rate showed a similar trend to the dynamic etch rate in colloidal silica slurry because no citrates were adsorbed on silica surfaces. The dynamic etch and removal rate of Cu were directly related to the type of abrasive particles in citric acid based slurry due to different absorption behavior.

10:30 AM *W7.6

Nanoporous Silica Based Slurries for Enhanced Chemical Mechanical Planarization of Low K/Ultra Dielectrics. Rajiv Singh[1], K. Choi[2], Marie Dufourg[2] and D. Singh[2]; [1]University of Texas, Austin, Texas; [2]Sinmat Inc., Gainesville, Florida.

The integration of low k dielectrics with copper metal lines is expected to considerably reduce RC (resistance x capacitance) delay for next generation CMOS devices. The low k dielectrics are typical fragile and are susceptible to both delamination, scratching and increased defectivity. We have demonstrated that the use of nanoporous nanosized silica particles for polishing of low k slurries leads to reduced delamination and surface defectivity. Using the modified Stobers process, porous silica particles of controlled size, surface area and total porosity were synthesized. The effect of various variables in controlling the particle size, pore size, and total porosity was determined, thereby enhancing our capability to tailor the characteristics of nanoporous silica particles. The pore size of the $<$ 100 nanometer particles varied from 5 A to 30A, whereas the total porosity can be varied from 0% to above 40. The nanoporous particles were found to exhibit much lower attractive van der Waals force compared to nonporous silica particles. For example, with 40% porosity, the measured Hamaker constant was more than a factor of 2 lower than nonporous silica particles. This is expected to lead to reduced adhesion of particles on polished surfaces. Using nanoindentation measurements, we have determined that the nanoporous particles exhibit enhanced elasticity, and reduced (and tunable) hardness (depending on porosity), thus making it ideal for use in low k polishing. The hardness of the particles can be reduced by almost a factor of 4 compared to nonporous silica particles. We have developed low k CMP slurries (also known as Step II slurries) based on nanoporous silica particles, which exhibit excellent characteristics including (i) reduced stress during polishing, (ii) reduced defectivity, (iii) high removal rate of tantalum and (iv) low removal rate of dielectric. We have demonstrated that the use of nanoporous silica particles in low k polishing slurries results in reduced surface defectivity and delamination during CMP polishing.

11:00 AM *W7.7

Challenges in CMP Slurry Management: Insights, Innovations, and Solutions. Benjamin R. Roberts, Liquid Abatement, BOC Edwards, Santa Clara, California.

The CMP process has steadily moved toward the status of a mature, ubiquitous technology. While much of the guesswork has been removed from CMP applications and consumables, many challenges remain. The formulation, storage, quality assurance, delivery, and disposal of CMP slurries require a large capital investment and high operating costs. The changing nature of CMP slurries imposes additional burdens on semiconductor fab facilities departments and QC labs. The extension of CMP to include process steps for copper, STI, and new barrier layer materials presents new challenges for slurry management. This paper first presents an overview of the challenges currently impacting CMP slurry management and slurry waste treatment. A historical perspective of the migration of slurry chemistries from simple oxide layer removal to multi-step copper and low-k dielectric planarization is provided. The effect of these changes on slurry behavior and handling is then developed and related to requirements for slurry storage, blend, and distribution equipment. Slurry metrology and quality assurance issues are reviewed. Examples of the stability and characteristics of mainstream slurries are used to define the key issues in slurry management. The typical slurry development and maturation cycle is used as a basis for predicting future trends and requirements for slurry management. Innovations in slurry management equipment are discussed, with an emphasis on the alternatives that are offered in the market and their comparative advantages. Of particular interest are prevention of changes to slurry chemistry and process performance and methods for measuring slurry quality at multiple points in the fab. Both dispense methods and blending technologies are considered. While CMP chemicals are relatively benign compared to other chemistries in the fab, environmental, health, and safety issues must be addressed. Water usage and disposal of liquid wastes from the CMP process impose large operating costs on the fab. The application of CMP to copper and other heavy metal layers has created a serious CMP waste disposal problem. Available methods for treatment of CMP liquid waste streams are compared. Advanced technologies for contaminant removal and water purification are discussed. Reuse of CMP wastewater is considered.

11:30 AM W7.8

The Intelligent Ceramic Slurry for Damascene Gate Process in ULSI. Ye-Hwan Kim[1], Sang-Kyun Kim[1], Ungyu Paik[1], Takeo Katoh[2] and Jea-Gun Park[2]; [1]Ceramic Engineering, Hanyang University, Seoul, South Korea; [2]Nano SOI Laboratory, Hanyang University, Seoul, South Korea.

Ceramic nanoparticle slurries play a central role in the successful development of chemical mechanical planarization (CMP) for ULSI processes. In order for the semiconductor device to achieve 50 nm or smaller linewidths, and multilevel interconnections, the reverse selectivity of CMP is required. Reverse selectivity has been used to planarize and remove the excess deposited Si3N4 film over patterned trench SiO2 film. To accomplish this process, a nano-sized ceria slurry has been employed. The chemical action from regents in the slurry leads to selective removal of the deposited film. In this study, the reverse selectivity performance was investigated with suspended nano-sized ceria using various slurry chemistries. The characteristics of the ceria slurry were determined from the viewpoint of colloidal science. The insights provided by electrokinetics, particle agglomeration, and rheology measurements predict the interface chemistry of the slurry which is then correlated to the CMP process parameters, such as removal rate, selectivity, and with-in wafer non-uniformity (WIWNU).

11:45 AM W7.9

Investigating the Effects of Diluting Solutions and Trace Metal Contamination on Aggregation Characteristics of Silica-Based CMP Slurries. Darren DeNardis[1,2], Hok-Kin Choi[2], Andy Kim[2], Mansour Moinpour[2] and Andrea Oehler[2]; [1]University of Arizona, Tucson, Arizona; [2]Intel Corporation, Santa Clara, California.

Silicon dioxide remains the most widely used inter-layer dielectric (ILD) in the semiconductor industry today. Non-planar SiO2 films on patterned wafers must be planarized using chemical mechanical planarization (CMP) before further processing. One of the major drawbacks to CMP is the tendency for abrasive particles in slurries to form aggregates, which have the potential to cause defects on wafer surfaces. Therefore, it is crucial to understand the mechanisms by which aggregates are formed so appropriate metrology can be identified that will identify defect-causing slurries before they are used in the fab. Single particle optical sensing (SPOS) techniques are commonly used to obtain large particle counts (LPC) for slurries prior to use in a fab. Other techniques that can be used to characterize slurries are static light scattering, dynamic light scattering and zeta potential measurements. All of these techniques usually require that the slurry be diluted prior to measuring. However, diluting with water changes the ionic strength and the pH of solution and both properties have been shown to affect aggregation and electric double layer characteristics of particles. This study shows that both known defect causing silica-based slurries and defect-free slurries demonstrate similar zeta potential, mean particle sizes and LPC using standard water dilutions. To quantify the effects of water dilution on zeta potential and mean particle size, an alternative diluting solution that simulates the ionic strength and pH of the original slurry was evaluated. While effects on mean particle size are slight, the alternative diluting solution demonstrates a decrease in magnitude of zeta potential of 30 mV as compared to the water-diluted slurries. In addition, it has been shown that relatively low concentrations of electrolytes can induce and propagate particle aggregation. The effects of doping silica-based slurries with aluminum added as a salt, an oxide and a hydroxide were also quantified in this work. The results indicate that rapid aggregation takes place when silica-based slurries are doped with 50 ppm Al added as aluminum chloride as verified by SPOS. Aluminum added as either oxide or hydroxide to slurries demonstrates no measurable particle aggregation using SPOS.

SESSION W8: STI CMP

Chair: Sharath Hosali
Thursday Afternoon, March 31, 2005
Room 2024 (Moscone West)

1:30 PM *W8.1

On the Mechanisms of Material Removal and Defect Generation in Shallow Trench Isolation (STI) CMP.

N. Chandrasekaran, Micron Technology, Inc., Boise, Idaho.

Shallow trench isolation (STI) is the preferred technology over local oxidation of silicon (LOCOS) for isolating semiconductor devices built on a silicon substrate. STI technology achieves isolation between active areas by patterning trenches into the silicon using nitride as a hard mask. Oxide is deposited to fill the trenches, which is also deposited over the nitride surface and requires to be removed. Chemical mechanical planarization (CMP) is the preferred methodology for removing excess oxide and achieving local and global planarization. The pattern dependence of CMP leads to non-uniform material removal across the entire wafer surface and requires over-polish to completely remove the oxide from the active areas (over nitride surface). This requires STI CMP to exhibit oxide-to-nitride removal selectivity, which is achieved primarily through the slurry-work surface interactions. Silica and ceria abrasives are used widely for STI CMP. In order to formulate optimized STI CMP slurries with high polish rate and selectivity, it is necessary to understand the differences in material removal mechanisms when polishing oxide and nitride surfaces with ceria- and silica-based slurries. In addition, scratches generated during STI CMP are of significant concern. Reduction in defects is partially enabled by reducing the number and size of large particles in the slurry distribution and altering the removal mechanisms. A reduction in the particle size distribution can also impact the process rate and stability. Also, particle size reduction can only provide defect improvement to a certain level. With constantly reducing dimensions and increasing density, the requirements placed on CMP process performance in terms of defect generation post-CMP has increased significantly. To enable significant defect reduction, alternate slurry technologies need to be investigated in detail. An improved understanding on the mechanisms of defect generation during the CMP process is also required. This paper explores the mechanisms of material removal and defect generation in STI CMP process. A detailed review of the STI CMP process is also presented.

2:00 PM W8.2

Effect of Physicochemical Characteristics of Nano Ceria Slurry on Shallow Trench Isolation CMP.

Sang-Kyun Kim[1], Ye-Hwan Kim[1], Ungyu Paik[1], Takeo Katoh[2] and Jea-Gun Park[2]; [1]Ceramic Engineering, Hanyang University, Seoul, South Korea; [2]Nano SOI Laboratory, Hanyang University, Seoul, South Korea.

The shallow trench isolation (STI) chemical mechanical planarization (CMP) performance was investigated as a function of physicochmical characteristics of nano ceria slurry. The fundamental particle characteristics and electrokinetic behavior of the ceria particles in aqueous suspending media were investigated to identify the correlation between colloidal property of ceria and STI CMP performance. The removal rate was influenced by the particle characteristics such as the crystallinity, grain size, and porosity. On the other hand, the oxide-to-nitride removal selectivity, within wafer non-uniformity (WIWNU), and the scratches of the polished surface were modulated with controlling the electrokinetic behaviors of the ceria particles and the SiO_2/Si_3N_4 films in aqueous media. Consequently, the physicochemical characteristics of nano ceria slurry were found to be key parameters in the STI CMP process.

2:15 PM W8.3

Characterization of the Chemical Effects of Ceria Slurries for Chemical Mechanical Polishing.

Jeremiah Terrell Abiade[1], Suresh Yeruva[1], Brij Moudgil[1] and Rajiv K. Singh[2]; [1]Materials Science & Engineering and Particle Engineering Research, University of Florida, Gainesville, Florida; [2]Microelectronics Research Center, University of Texas, Austin, Texas.

For highly selective particle-based slurries or fixed abrasive pads, ceria has been identified as the abrasive of choice for the chemical mechanical polishing (CMP) step for shallow trench isolation (STI). The advantageous performance of ceria-based CMP consumables is usually attributed to enhanced chemical reactivity between ceria and oxide materials. In fact, this reaction is a central theme of all ceria polishing models from glass polishing to STI CMP. Previously, experimental evidence in support of the ceria-silica reaction during CMP was virtually non-existent. Recently, we proposed a pH-dependent ceria-silica polishing mechanism based on polishing results, in-situ friction force measurements, and spectroscopic and microscopic investigations. In this report, further x-ray photoelectron spectroscopy (XPS), scanning electron microscopy (SEM), atomic force microscopy (AFM) studies are reported and correlated to the polishing performance of ceria-based slurries. AFM silicon tapping mode cantilevers were functionalized by depositing a silica coating via chemical vapor deposition. SEM imaging and compositional analysis was conducted on the cantilevers before and after wear against a ceria thin film, which was grown by pulsed laser deposition. The cantilever wear profile and elemental composition as a function of pH confirms our earlier polishing results and the pH-dependent CMP model for ceria-silica CMP.

2:30 PM W8.4

A Study of Chemical Mechanical Planarization Process for Shallow Trench Isolation.

Ashok Kumar[1,2] and Parshuram Bakrishna Zantye[1,2]; [1]Department of Mechanical Engineering, University of South Florida, Tampa, Florida; [2]Nanomaterials and Nanomanufacturing Research Center, University of South Florida, Tampa, Florida.

Shallow Trench Isolation (STI) has become a key technology for device isolation in recent times. The process of fabrication of STI structures is still under considerable research. Until now, a complicated reverse moat etch process had to be used in the absence of sufficiently selective slurries for SiO2 to Si3N4 polishing. One of the main areas of interest is development of silica and ceria based high selectivity slurries (HSS) with a high polishing selectivity for silicon oxide and silicon nitride. In this research, we have compared the performance of standard SiO2 polishing slurry with the high selectivity slurry (HSS) during STI planarization. The polishing experiments were performed on the CETR Bench top CMP tester. The variation of coefficient of friction (COF), acoustic emission (AE) and process end point were detected in situ. Ex situ metrology for other CMP out put parameters such as removal rate, slurry selectivity and surface defects was also performed. The knowledge of COF and removal rate enables the determination and elucidation of the polishing mechanism for the given slurry. The data was compared with the already existing material removal rate (MRR) model for STI structures.

2:45 PM W8.5

High Selectivity, Colloidal Silica based STI CMP Slurry.

Kyoung-Ho Bu[1,2] and Brij M. Moudgil[1,2]; [1]Materials Science and Engineering, University of Florida, Gainesville, Florida; [2]Engineering Research Center for Particle Science & Technology, University of Florida, Gainesville, Florida.

Among various properties of chemical mechanical polishing (CMP) slurry, selectivity plays a key role for global planarization of high density and small pattern size shallow trench isolation (STI) process in terms of various defects such as dishing and erosion. To improve the selectivity of STI CMP process, CMP characteristics of silica and silicon nitride wafer using colloidal silica slurry as a function of slurry pH has been conducted. Sodium dodecylsulfate (SDS), which is anionic surfactant, has been added to the slurry to increase the selectivity of the slurry. As a result, selectivity of more than 25 compared with 3 without SDS was accomplished. It was concluded that selective passivation layer formed on silicon nitride wafer surface at acidic slurry pH range. Adsorption characteristics of SDS on silica and silicon nitride were studied as a function of slurry pH and concentration of SDS. As indicated by zeta potential behavior of silica and silicon nitride, adsorbed amount of SDS increased exponentially on silicon nitride but not on silica at highly acidic slurry pH due to the high electrostatic attraction, which resulted in the selective passivation layer on silicon nitride and high selectivity of the slurry.

SESSION W9: Novel Planarization Processes and Applications

Chair: S. Balakumar
Thursday Afternoon, March 31, 2005
Room 2024 (Moscone West)

3:30 PM *W9.1

Electro Chemical Mechanical Planarization Process-High Planarization Efficiency and Wide Removal Rate Window. Feng Liu, Alain Duboust, Stan Tsai, Antoine Manens, Siew Neo, Yan Wang and Liang Chen; Applied Materials, Sunnyvale, California.

Electro Chemical Mechanical Planarization (Ecmp) provides an extension of the conventional CMP process into the 65nm technology node and beyond by providing extendibility for low k materials due to the low mechanical down force. In addition, the electrochemical removal mechanism has superior planarization efficiency, high removal rate and an excellent within-wafer profile control. Multiple electrical zones (cathode) configuration combined with a precise end-point control by electric charge (electric current with time), make the remaining thickness and profile of Copper film more predictable and controllable. Planarization efficiency is always a top priority in CMP process for throughput improvement, process reliability and cost saving. The factors affecting the planarization such as the concentration and the efficiency of the inhibitors will be discussed in this paper. Efficiency-evaluation method of the inhibitors will be illustrated to involve the strength and rate of passivation. Through the evaluation method, the efficiency of inhibitors is transferred into planarization efficiency of CMP process on Ecmp tool. Meanwhile a planarization mechanism for Ecmp will be proposed to match the high planarization efficiency. The electrical feature allows Ecmp to be a planarization process independent on down force and thus have a wide removal rate window ranging from 0.1um/min to approximately 1 um/min. When varying the down force while maintaining the same voltage, the removal rate remained the same, indicating the independence of the removal rate on the down force. When varying the voltage and maintaining the same down force, the removal rate changes proportionally with the applied voltage, indicating that applied voltage is a controlling parameter in removal rate. The removal rate is also proportional to the electrolyte conductivity. The effects of applied voltage and the electrolyte conductivity (both affecting removal rate) will be presented in this paper. In summary, the planarization performance, the removal rate and the fundamentals of the Ecmp process will be discussed in this paper. The linear relationship between the removal rate and applied voltage will be presented to demonstrate low down force capability of Ecmp.

4:00 PM W9.2

Advanced ELID Process Development for Grinding Silicon. Mohammad Majharul Islam[1], A. Senthil Kumar[1], S. Balakumar[2], H. S. Lim[1] and M. Rahman[1]; [1]Mechanical Engineering, National University of Singapore, Singapore, Singapore; [2]Institute of Microelectronics, Singapore, Singapore.

The achievement of the Silicon on Insulator (SOI) substrate has opened up the likelihood of co-integration of photonics and electronics. To stop unwanted leaky currents towards the substrate in standard CMOS electronics, this substrate has been primarily developed. However, downsizing devices has brought challenges to the manufacturing processes for surface nano-topography of the silicon materials. Achieving thin silicon in SOI with good uniformity is one of the challenges and it will more difficult for 300 mm wafers. Currently the grinding and final finishing of the wafer is done by conventional grinding and Chemical Mechanical Polishing (CMP) processes. These processes have, however, some disadvantages such as poor machinability, waste water problem and high manufacturing cost. Efficient machining is, therefore, essential for grinding silicon wafer more cost effectively with nano-scale surface accuracy. A novel ELID grinding technique realizes mirror quality surface of silicon wafer, and the process has started to take the place of substrate thinning for Silicon on Insulator and also potentials for polishing processes [1]. However, the comparative analysis of the performances between ELID grinding and CMP processes has not yet been done. In this study, the ELID grinding method has been significantly modified and used to grind silicon wafers, and the machining performance of this modified ELID grinding process have been compared with that of CMP process. The modified ELID grinding experiments were carried out on a CNC machining center with 1?m depth of cut. CIB-D cup wheel of grit size #8000 was used for this process. The CMP experiments were carried out on a CMP polisher with 1?m/min material removal rate. The used loose abrasives in CMP process were 30-90nm in size. The work piece was the mono crystalline silicon wafer of 152.4 mm in diameter. Mitutoyo Formtracer was used to measure surface roughness of machined wafers. In addition, AFM, SEM and EDX analyses were performed on the machined silicon wafer surfaces. While the average surface roughness exhibited by both processes was similar (2nm), the maximum surface roughness was significantly better in modified ELID grinding process (14nm). The ground wafer surfaces observed under SEM and AFM showed comparable results with those of polished wafer surfaces. Based on the comparative study carried out on the performances between modified ELID grinding and CMP processes for machining silicon wafers, it can easily be said that the modified ELID grinding process can exhibit comparable performance with CMP process. It appears that the modified ELID grinding process has great potential to meet the challenge of "faster, finer and cheaper" in machining silicon conquering grinding processes for wafers. [1] H. Ohmori, T. Nakagawa, Mirror surface grinding of silicon wafers with electrolytic in-process dressing, Annals of the CIRP, Manufacturing Technology, 39/1/1990, pp. 329−333.

4:15 PM W9.3

Selective Chemical-Mechanical Planarization of Polysilicon during Fabrication of Micro-Electro-Mechanical-Systems Devices. Anita Natarajan, Sharath Hegde and S. V. Babu; Department of Chemical Engineering, Clarkson University, Potsdam, New York.

Chemical-mechanical planarization (CMP) has become an enabling technology in the manufacturing of micro-electro-mechanical-systems (MEMS) devices. During the fabrication of moving parts in multilevel structures for MEMS devices, severe uneven topography results from the deposition and etching of several microns thick polysilicon and silicon dioxide films, similar to IC devices. Hence CMP is used to planarize these layers. In a typical CMP process in MEMS device fabrication, the polysilicon top layer has to be polished with a slurry that yields high polysilicon film polish rates as well as high removal rate selectivity with respect to the underlying silicon dioxide/nitride. In this work, polishing was performed on blanket polysilicon, silicon dioxide and silicon nitride films using slurries containing ceria/silica particles and several different additives. The additives play a crucial role in suppressing the oxide and nitride removal rate while also enhancing the polysilicon rate in some cases. Polysilicon polish rate as high as $\sim$ 500 nm/min and polish rate selectivity with respect to both oxide and nitride removal that is as high as $\sim$ 290:1 was achieved with these slurries. Zeta potential data and infrared spectroscopy of the film surfaces in the presence of these additives were used to explain the selective removal of the polysilicon film over silicon dioxide/ nitride films.

4:30 PM W9.4

Embedded Benzocyclobutene Islands in Silicon (EBIS) Process for Fabrication of Electrostatic Microelectromechanical Devices. Alireza Modafe, Nima Ghalichechian and Reza Ghodssi; Department of Electrical and Computer Engineering, University of Maryland, College Park, Maryland.

This paper reports a novel fabrication process to develop planarized isolated islands of benzocyclobutene (BCB) polymer embedded in a silicon substrate. Embedded BCB islands in silicon (EBIS) can be used as an alternative to silicon dioxide in fabrication of electrostatic micromotors, microgenerators, and other microelectromechanical devices where a planarized thick film is needed to provide electrical, mechanical, and thermal isolation. BCB was primarily used as an interlayer dielectric (ILD) in microelectronics. Considering its low dielectric constant (k=2.65), application of thick BCB as insulating layer enables the development of electrostatic devices with minimal parasitic capacitances, leading to minimal electrical energy loss. Furthermore, BCB has a low residual stress (28 MPa) and a low thermal conductivity (0.29 W/m.K), enabling its application as a structural material as well as a thermal isolator. The major process steps in development of EBIS are as follow. The island areas as large as 5 mm by 10 mm and as deep as 10-15 μm are etched in silicon using conventional photolithography and reactive ion etching (RIE) processes. Photosensitive BCB (CYCLOTENE 4026-46) is spun on, patterned and then planarized using chemical mechanical planarization (CMP). This process flow is repeated twice to completely fill and planarize the islands. The BCB pattern area is designed to be larger than the island area by 5 μm on each side to prevent formation of voids after planarization. The first BCB layer is not cured to achieve higher removal rate in planarization step. The second BCB film, however, is cured at 200 °C for 40 minutes to be partially cross-linked to the first BCB layer before the second CMP step. This procedure prevents the second BCB layer from being peeled off during CMP process. Atomic force microscopy and elipsometry of blanket BCB films before and after CMP show that higher polishing down force and speed lead to higher removal rate in expense of higher surface roughness, non-uniformity, and scratch density. This is expected knowing that BCB is a softer material compared to inorganic films such as silicon dioxide. The CMP removal rates of the BCB ridges using an ammonium-hydroxide-based slurry with 175-nm silica abrasives are 1.5 μm/min for uncured BCB and 0.9 μm/min for cured BCB. We have observed that as the cure temperature of BCB increases beyond 200 °C, the CMP removal rate decreases drastically.

The optical and scanning electron microscopy, as well as optical and contact profilometery of the isolated BCB islands exhibit excellent planarized surfaces. An average step height reduction of more than 90 % was achieved using EBIS process after two BCB deposition and CMP steps. This result demonstrates EBIS as an integrative process technology for development of thick planarized embedded islands of BCB polymers in silicon, enabling fabrication of electric micromachines with electrical, mechanical, and thermal isolation.