SYMPOSIUM E

Fundamentals and Materials Issues in Chemical-Mechanical Polishing of Materials

April 26 – 27, 2000

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* Invited paper

SESSION E1: CMP MECHANISMS
Chair: Mansour Moinpour
Wednesday Morning, April 26, 2000
Salon 12 (Marriott)

8:30 AM *E1.1
INTERACTION OF SURFACES IN CHEMICAL MECHANICAL POLISHING PROCESSES. Brij M. Moudgil, Bahar Basim, Joshua J. Adler, University of Florida, Engineering Research Center for Particle Science and Technology and Department of Materials Science and Engineering, Gainesville, FL.

The local and global planarity of a polished surface is critically dependent on the abrasive particle size distribution as well as the interactions between particles suspended in the polishing slurry and the surface. In this investigation, the effect of a small concentration of oversized particles on the removal rate, local planarity, and damage generation is experimentally determined and analyzed from the perspective of polishing mechanism. Small changes in the tails of the particle size distribution are found to have a significant influence on the polishing output parameters and highlight the differences between mechanically activated chemical processes and mechanical polishing. Chemical mechanical polishing (CMP) techniques often employ extreme pH conditions or high concentrations of oxidizer or other additives such that theoretical predictions of stability and adhesion force may not be valid. Additionally, the precise behavior of dispersants, especially in corrosive environments, is relatively undefined. To prevent oversized particles due to abrasive agglomeration and limit particulate contamination of the substrate while not adversely affecting polishing performance advanced reagent schemes must be developed. The importance of stability in CMP systems as well as control methodologies will be discussed with a specific example being that of a reagent scheme designed to impart stability to high ionic strength suspensions and its application to CMP.

9:00 AM E1.2
THE EFFECTS OF WAFER SHAPE ON SLURRY FILM THICKNESS AND FRICTION CORRELATIONS IN CHEMICAL-MECHANICAL PLANARIZATION. Joseph Lu, Chris Rogers, Vincent Manno, Jonathan Coppeta, Livia Racz and Alicia Scarfo, Tufts University, Dept. of Mechanical Engineering, Medford, MA; Ara Philipossian, Intel Corp., Santa Clara, CA; Frank Kaufman, Cabot Corp., Aurora, IL.

The fluid film thickness and drag during chemical-mechanical polishing is largely dependent on the shape of the wafer polished. In this study we use dual emmission laser induced flourescence to measure the film thickness and a strain gage mounted on the polishing table to measure the friction force between the wafer and the pad. All measurements are taken during real polishing processes. The trends indicate that with a convex wafer in contact with the polishing pad the slurry layer increases with increasing platen speed and decreases with increasing downforce. The drag force decreases with increasing platen speed and increases with increasing downforce. These cases are true for both in-situ and ex-situ conditioning. However, these trends are significantly different with the case of a concave wafer in contact with the polishing pad. During ex-situ conditioning the trends are the same as with a convex wafer. In-situ conditioning, however, decreases the slurry film layer with increasing platen speed, and increases it with increasing downforce. The drag force increases with increasing platen speed as well as increasing downforce. Since we are continually polishing, the wafer shape does change over the course of each experiment causing a larger error in repeatability than the measurement error itself. Different wafers are used throughout the experiment and the results are consistant with the variance of the wafer shape. Local pressure measurements on the rotating wafer help explain the variences in fluid film thickness and friction during polishing.

9:15 AM E1.3
STRESS DISTRIBUTION AT THE WAFER SURFACE IN A CMP PROCESS. Lav Agarwal, Chang-Won Park, University of Florida, Dept of Chemical Engineering, Gainesville, FL.

The mechanical effects on material removal in a CMP process is studied by investigating a combined problem of fluid dynamics of slurry flow and solid mechanics of wafer deformation. The stress imposed by the slurry flow on the wafer surface with microscopic features is determined numerically using a finite difference method. The stress at the surface is, then, used as a boundary condition to investigate the stress state inside the wafer. Once the stress distribution inside the wafer is known, yielding of material, hence the removal of the material from the wafer surface may be predicted by applying the Von Mises criterion. The present approach is, in a sense, a combination of Runnels physical model and yield stress model. Details of the calculated results for various feature sizes, shapes and distribution will be discussed.

9:30 AM E1.4
A THEORY OF THE CHEMICAL ASPECTS OF CMP. Ed Paul, Stockton College, Pomona, NJ; NIST, Gaithersburg, MD.

A theory separating the chemical and mechanical aspects of CMP is presented, providing a quantitative description of the dependence of polishing rate on the concentration of reactive chemical in the slurry. Qualitatively, the polishing rate increases with concentration at low concentration and becomes constant at high concentration. Polishing proceeds when a chemical component of the slurry attacks a site on the surface being polished, thereby changing the surface bonding. Mechanical action breaks the weakened bond easily, polishing occurs, and fresh surface is presented. At low concentrations, the fraction of surface sites available for reaction is low, so the polishing rate, limited by reactant, is proportional to slurry concentration. At high slurry concentrations, most surface sites are filled, additional reactant has little effect, and the polishing rate becomes constant. Quantitative comparison of the model with experimental data will be provided.

10:15 AM E1.5
TRANSIENT AND STEADY STATE ELECTROCHEMICAL EFFECTS AND ITS CORRELATION TO CHEMICAL MECHANICAL POLISHING REMOVAL RATES DURING METAL CHEMICAL MECHANICAL POLISHING. Rajiv K. Singh, Uday Mahajan, Seung-Mahn Lee, Anupam Nagory and Zhan Chen, Dept. of Materials Science and Engineering and Engineering, Research Center for Particle Science and Technology, University of Florida, Gainesville, FL; Pankaj Agarwal and Dieter Landolt, Dept. of Materials Science, Ecole Polytechnique Federale Lausanne, Lausanne, SWITZERLAND.

The CMP process using particle based slurries involved both transient surface chemical reaction due to interaction of chemicals and particles with metal surfaces. Numerous electrodynamic (such as potentiodynamic) studies mentioned in the literature show a large degree of discrepancy between the CMP removal rates and the electrochemical reaction rates. In the talk,we will present data based on transient as well as steady state measurement so as to understand the electrochemical effects in W and Cu CMP. Based on electrochemical measurements and tribochemical measurements, correlations between the CMP removal rate and chemical reaction rates will be determined. The mechanism for CMP removal rates will also be discerned.

10:30 AM E1.6
MODELING ON MECHANICAL PROPERTIES OF POLISHING PADS IN CMP PROCESS. Takeshi Nishioka, Satoko Iwami, Takashi Kawakami, Toshiba Co, Corporate Reseach & Development Center, Kawasaki, JAPAN; Yoshikuni Tateyama, Hiroshi Ohtani, Naoto Miyashita, Toshiba Co, Semiconductor Company, Yokohama, JAPAN.

Chemical mechanical polishing is an essential process for achieving a high degree of planarization. The planarity after CMP sensitively depends on pattern scales, pattern densities and mechanical properties of polishing pads. In order to simulate the topography after CMP, a numerical model for the polishing pad is proposed. In this model, the surface roughness layer of the polishing pad is assumed as a flat soft layer. The distribution of the contact pressure between the patterned wafer and the polishing pad is calculated with finite element method, and the pattern topography is modified based on the pressure dependency of the polishing rate. The iterations of the contact pressure analyses and the topography modifications give the progress of the polishing process numerically. The model is applied to oxide CMP process with silica slurry and stacked pad of polyurethane and non-woven fabric. The compressive elastic moduli of polyurethane layer and non-woven fabric layer are measured dynamically. The ratio of the elastic modulus of the soft layer to that of polyurethane layer is treated as a fitting parameter between the experimental results and the numerical model. The models with the ratio of 1/25 to 1/30 show good agreement with experimental results in both of a short range, where the compressive deformation of the pad is dominant, and a long range, where the bending deformation is dominant. Static measurement for the surface elasticity of the polyurethane layer also gives a good agreement with the model. The proposed pad model should be useful for the topography simulation, and it also guides the development of new polishing pads.

10:45 AM E1.7
FUNDAMENTAL STUDIES ON THE MECHANISMS OF OXIDE CMP. Uday Mahajan, Seung-Mahn Lee and Rajiv K. Singh, Department of Materials Science and Engineering and Engineering Research Center for Particle Science and Technology, University of Florida, Gainesville, FL.

In this talk, we present the results of a systematic study on the mechanisms of the chemical-mechanical polishing (CMP) of silicon dioxide. Earlier studies by us have shown the effect of particle size and solids loading in SiO_2 CMP. In this study, polishing experiments were conducted with SiO_2 slurries to which different concentrations of metal halide salts (LiCl, NaCl and KCl) were added to promote agglomeration of the abrasives. The results clearly show that formation of soft agglomerates enhances polish rate, and does not affect surface roughness significantly. Differences in polish rate for different salts, especially at high salt concentrations, could be attributed to the thermodynamics of salt dissolution. In the second part of this study, abrasives of different types (SiO_2, Al_2O_3, CeO_2, ZrO_2, TiO_2) with similar particle sizes were used to conduct polishing experiments. Polishing was carried out using 2 vol.% slurries for four different pHs. The results showed a clear dependence of polish rate on the nature of the abrasive, with CeO_2 showing the highest polish rate. In addition, significant particle deposition was observed on the SiO_2 wafer surface at the point of minimum stability of the different abrasives.

11:00 AM E1.8
DOUBLE-KINK THEORY APPROACH IN CMP MODELING.
Valeriy Sukharev, LSI Logic Corporation, Santa Clara, CA.

Current efforts in CMP modeling can be divided into two groups. The first group represents the efforts to model CMP on the basis of stress/strain distributions that exist in the pad-slurry-wafer systems. The second group deals with the chemical aspects of CMP modeling. The present study focuses on modeling the polishing process by surface atom dissolution enhanced by mechanical stressing. The primary focus is to explain the dependence of the polishing rate on the pattern density and to express dishing, erosion and planarization phenomena as functions of the pattern structure. The approach is based on the double kink mechanism of nuclei formation and growth. This approach succeeds in predicting both the relative and absolute polish rates for a variety of arrays with different pattern densities. A polishing process is described in this model as resulting from formation of a critical size pit (nuclei) on the surface terrace by means of the dissolution of a group of atoms enhanced by the applied mechanical pressure. It is followed by growth of the freshly nucleated pit by means of a step edge motion initiated by the stress enhanced dissolution of any step edge atom and followed by the fast dissolution of the newly formed corner atoms. This mechanism can be described as formation of a double kink site at the step edge, followed by motion of the single kinks. The time required for dissolution of the entire surface layer is determined by the time for the critical pit nucleation and for the annihilation of the neighboring pits. Assuming applicability of the Zhurkov-Arrhenius expression for the stress-enhanced rate of the atom dissolution, we can derive the experimentally confirmed sub-linear pressure dependence in Presttons equation. The most important parameter derived from the model is the mean distance between the critical pits or, in other words, the average distance traveled by the step before it is annihilated by another step. Depending on the interrelation between this pressure dependent critical length and a characteristic size of the polished pattern different removal kinetics can be expected. This new physically based model can describe the metal dishing and oxide erosion rates in a variety of pitch structures and predict the dependence of the ILD planarization time as a function of pre-CMP profile and major process parameters, such as mechanical pad characteristics, applied pressure, relative pad-wafer velocity.

SESSION E2: DIELECTRIC AND METAL CMP
Chair: Marc Meuris
Wednesday Afternoon, April 26, 2000
Salon 10/11 (Marriott)

1:30 PM E2.1
SURFACE CHARACTERISTICS OF COPPER THIN FILMS DURING CHEMICAL-MECHANICAL POLISHING. Wei-Tsu Tseng, James Niu, Rick Lu, Dept of Materials Science & Engineering, Tainan, TAIWAN.

The introduction of damascene and dual-damascene processes for ULSI multilevel interconnects beyond 0.25um generation has prompted the development of chemical-mechanical polish (CMP) for Cu thin films. Unlike Al, Cu forms a thin porous surface oxide layer, which offers minimum protection for Cu against oxidation and corrosion. The cyclic formation and removal of this surface oxide is critical to the mechanism of Cu CMP. While the formation of this porous oxide layer depends strongly on the chemical characteristics (e.g., pH and oxidation potential) of the slurry used, the removal of it may bear a dual chemical and mechanical nature. Results of our preliminary study show that the frictional force during Cu CMP is sensitive to the pH in the acidic range, using a alumina-based peroxide slurry. In addition, the surface roughness of post-CMP Cu is independent of the down force applied, but is correlated to the pH and frictional force. Given a fixed solid loading in the slurry, the above results imply that the change frictional force bears a strong dependence on the chemistry involved, in addition to the adhesion force between particles and wafer surface. To further clarify the mechanism involved in Cu CMP, frictional force during Cu CMP will be measured using near-neutral slurry (pH 7). Oxidation potential will also be derived from electrochemical measurements. TEM and AFM will be employed to analyze the surface microstructure of pre- and post-CMP Cu surface. For comparisons, the same experiments will be performed on Cu films immersed in flowing slurry without abrasion. Frictional behavior, electrochemical measurements, and surface characteristics of TaN films with Cu slurry and Ta/TaN slurry will also be investigated. The behaviors exhibited by Cu and TaN will be compared so as to help unravel the mechanism during Cu CMP for damascene-based Cu interconnects.

1:45 PM E2.2
CHEMO-MECHANICAL POLISHING AND ATOMIC FORCE MICROSCOPIC STUDY OF SiC SUBSTRATES. P.S. Dutta, R.J. Gutmann and T.P. Chow, Dept. of Electrical, Computer and Systems Engineering, Center for Integrated Electronics and Electronics Manufacturing, Rensselaer Polytechnic Institute, Troy, NY.

A variety of diamond, alumina, silica and chromium based slurries have been evaluated along with several different types of pads for the chemo-mechanical polishing of as-received 4H and 6H SiC commercial substrates. Even though scratch free surfaces could be obtained by the chromium and silica based slurries, the relative removal rates have been found to be extremely low and anisotropic on the Si and C- faces of SiC. On the other hand, alumina based slurries have low to moderate removal rates, but are not effective in eliminating fine scratches. Diamond based slurries possesses both the advantageous features of high removal rates and complete elimination of surface scratches. By progressively decreasing the abrasive particle sizes (e.g., from 6 to 0.25 micron) in discrete steps, complete removal of scratches could be achieved. Surface roughness (as evaluated through Atomic Force Microscopic measurements) $\sim$ 0.2 nm in 10 micron X 10 micron areas have been repeatedly demosntrated after the final polishing step with 0.25 micron abrasive size diamond slurry; this roughness is comparable to device quality Si wafer micro-roughness (0.15 nm over 1 micron X 1 micron areas). The role of pad materials on the removal rates and effectiveness in scratch elimination will be presented. Based on these considerations and pad lifetime, Multi-Tex pad (from South Bay Technology) has been found to be suitable for SiC CMP. Apart from the wet chemo-mechanical polishing with above slurries, dry mechanical polishing using diamond and alumina abrasive films with various grits were also attempted. While the alumina films result in severe scratching, totally scratch free surfaces could be obtained with diamond films. The removal rates of diamond abrasive film was found to be extremely high ($\sim$ 50 microns/hr with 1 micron size abrasive film). The only disadvantage of the abrasive films is the poor lifetime. Post CMP cleaning is a major issue for SiC. The abraded SiC particles stick to the surface and are extremely difficult to remove either with brush or ultrasonic cleaning. Several different substrate preparation recipes like RCA cleaning have been found to be ineffective. To certain extent, polishing in pure de-ionized water or organic solvents on a fresh pad (after CMP) resulted in removal of the large clusters of particles. Methodologies for complete removal of surface particles, such as usage of surfactants and sacrificial high temperature oxidation and etching, will be discussed.

2:00 PM E2.3
ANALYSES OF COPPER DAMASCENE STRUCTURES AND CHEMICAL-MECHANIAL POLISHING. Tae-Soon Park, Subra Suresh, Massachusetts Institute of Technology, Dept of Materials Science and Engineering, Cambridge, MA.

As reduction of device and interconnect dimensions continues to drive the semiconductor industry toward faster and denser integrated circuits, the reliability of metal interconnect lines becomes critical for device performance. Due to difficulty in the etching of copper, the chemical-mechanical polishing (CMP) process is introduced. This presentation will describe new theoretical and computational analyses of the Damascene process for unpassivated and passivated copper interconnect lines with the objective of estimating curvatures and stresses along and across the lines for various process conditions, thermal loading, and a wide variety of practically relevant trench, line and passivation geometries. The predictions of the analyses will be compared with experimental observations. The geometrical effects of thermomechanical deformation as a consequence of chemical-mechanical polishing are also examined systematically.

2:15 PM E2.4
PLANARIZATION OF COPPER AND TANTALUM FILMS USING ALUMINA AND SILICA ABRASIVES - A COMPARISON. S. Ramarajan[a], Y. Li[b], M. Hariharaputhiran[a], Y.S. Her[c] and S.V. Babu[a,d], Departments of [a]Chemical and [b]Mechanical Engineering, [c]Ferro Corporation, Penn Yan, NY, [d]Center for

Advanced Materials Processing, Clarkson University, Potsdam, NY.

Abrasives play an important role during chemical-mechanical planarization (CMP) process not only to enhance the polish rates but also in reducing defects such as micro-scratches and in minimizing dishing and erosion. Alumina and silica are widely used as abrasives for Cu and Ta CMP. While alumina is harder than silica and hence gives higher polish rates, cost concerns favor the use of silica abrasives. This paper will discuss copper and tantalum polishing results using alumina and silica abrasives in the absence and presence of various slurry chemistries. The use of alumina and silica abrasives for CMP of Cu and Ta results in very different mechanisms of polishing. The polish rates in alumina slurries vary in accordance with the hardness of the film being polished, suggesting a dominant role for a wear mechanism. However, the rates in silica slurries do not relate directly to the hardness of the film, indicating a more complex removal mechanism. Experimental results on Cu and Ta polish in the absence and presence of different slurry chemistries such as ferric nitrate, hydrogen peroxide-glycine, ammonium persulfate etc., using both silica and alumina abrasives will be presented. These rates will be related to the measured hardness values of the as deposited films and of the films exposed to several slurry chemistries. Additionally, changes in pH and ionic strength of the slurry modify the zeta potential and the width of the electrical double layer of both the abrasives and the polishing surface and have a profound impact on the polishing process. This effect will also be discussed as it applies to copper and tantalum CMP using alumina and silica abrasives. Finally, an extensive set of electrochemical (both *ex situ* and *in situ* during polishing) measurements will be presented and related to the polishing mechanisms for Cu and Ta.

2:30 PM E2.5
FUNDAMENTAL INVESTIGATION OF Cu CMP: PART I, EXPERIMENTAL EVIDENCE. Hong Liang, University of Alaska Fairbanks; Jean-Michel Martin, Beatrice Vacher, Ecole Centrale de Lyon; Vlasta Brusic, Cabot Corporation.

In this work, we used two experimental approaches to study mechanisms of chemical-mechanical polishing of copper. Electrochemical analysis was conducted to evaluate the copper dissolution and abrasion rate of the slurry. Results showed that with abrasion effect copper was removed at a rate of 70-100 A/min and was corroded at a rate of 2 A/min. In alkaline pH region of oxide polishing slurries, Cu tended to passivate and evidence of passivation was noticeable even with abrasion. Another approach was to use a field-emission high-resolution analytical TEM and X-ray spectroscopy to analyze polishing components. Results showed evidence of chemical wear of copper due to polishing. In this presentation, we discuss these two competing mechanisms of copper removal during CMP.

SESSION E3: POSTER SESSION: CMP MECHANISMS
Wednesday Evening, April 26, 2000
8:00 PM
Salon 1-7 (Marriott)

E3.1
CHEMICAL MECHANICAL DEPOSITION – A NEW WAY OF GENERATING ATOMICALLY FLAT SURFACES. Rizal Hariadi, Steve Langford, Tom Dickinson, Washington State University, Dept. of Physics, Pullman, WA.

When you have a dent in the wall one does not wear away square meters of wall to make it flat–you fill in the dent with putty. In terms of energy and time, considerable savings can be achieved on nearly flat surfaces by such an approach. We show for the first time that layer by layer crystal growth can be controlled mechanically in such a fashion that 'fills in' micron-sized features a few atomic layers deep. The experiments are done under supersaturated solution conditions. Step edges are stimulated with low contact force scanning using a scanning force microscope (which is also used to image the changes in surface topography. We present recent results on single crystal brushite ($CaHPO_4.2H_2O$) where we find strong dependencies on solution chemistry, mechanical parameters (e.g., normal force), and step crystallography. A model for the mechanism involving solution confinement will be presented.

E3.2
SURFACE EFFECTS DURING PLASTICITY AND FRACTURE OF SOLIDS. Valery P. Kisel, Inst. of Solid State Physics, Chernogolovka, Moscow Distr., RUSSIA.

Although the softening or hardening effects of various surface treatments (surface polishing-Ioffe effect for solids, IE; surface/subsurface impurity segregation, hard surface films, coatings and oxidation, electro-physical effects, corrosion, etc.) under micro-, macrodeformation have been studied thoroughly, and these effects have many common features for different classes of materials,there is no consensus about the nature of these phenomena till now. This work deals with the IE on microplasticity (mobility and multiplication of dislocations) and fracture in model ionic crystals under successively applied compressive-tensile stresses, s (s=0.9S to 95S, where S is the resolved yield stress) and stress rates (0.0001 to 1 000 000 MPa/sec)was investigated in the temperature range T =4.2 to 1023K (0.002 to 0.96)Tmelt, Tmelt is the melting point). The subsided motion/multiplication of dislocations were most manifested for low T $< 80K$. Having covered a certain pathlength determined by crystal and test parameters, the dislocations undergo multiplication. The stress, stress rate and temperature dependences of mean pathlengths before multiplication are similar to the appropriate macroscopic deformation - stress work-hardening curves. After polishing of the near-surface layer with the thickness h (5 microns $< h <$ 35 microns) the dislocations stopped by previous loadings begin to move/ multiplicate till the next full stop (micro-IE). Surface films and various treatments, environments prevent conservative motion of stress-aided jogs/kinks along the dislocations to and from the sample surface thus pumping the impurity phase/jogs out or into the crystals and retarding dislocations and changing the electrical, chemical, etc. surface-environment interactions, prompting the subsurface/crystal bulk hardening or softening.

SESSION E4: POSTER SESSION: DIELECTRIC AND METAL CMP
Wednesday Evening, April 26, 2000
8:00 PM
Salon 1-7 (Marriott)

E4.1
A NOVEL SINGLE STEP LAPPING AND CHEMO-MECHANICAL POLISHING SCHEME FOR ELEMENTAL AND COMPOUND SEMICONDUCTOR MATERIALS USING $1\mu m$ ALUMINA SLURRY. P.S. Dutta and R.J. Gutmann, Dept. of Electrical, Computer and Systems Engineering, Center for Integrated Electronics and Electronics Manufacturing, Rensselaer Polytechnic Institute, Troy, NY; D. Keller, Universal Photonics Inc., Hicksville, NY; and L. Sweet, Baikowski International Corp., Charlotte, NC.

Using a agglomerate-free, alumina slurry with 1 micron abrasives (from Universal Photonics Corp. and Baikowski International Inc.), rapid removal of semiconductor materials has been achieved with atomically- smooth surfaces. Materials studied include: GaSb, InGaSb, InGaAs, InAs, GaAs, InSb, InGaAsSb, CdTe, CdZnTe, Si and Ge. Surface damage resulting from wafer slicing could be removed by using the 1 micron slurry with high removal rates, resulting in mirror smooth surfaces. This new finding has implications in terms of reduced sub-surface damages during lapping and polishing, elimination of cracks in ternary and quaternary substrates and avoidance of slurry cross-contamination problems (with multiple slurries). The results of the single step lapping and polishing using the present slurry have been found to be superior and the process simplified compared to the conventional strategies, wherein lapping and polishing proceed in several discrete steps starting from large abrasive particle (18-30 micron) and terminating in less than 1 micron abrasive. The effect of different pad materails has also been evaluated. The removal rates have been found to be independent of the pad material for the pads evaluated to-date with soft and hard pads showing similar results. Advantageously, soft pads like velvets reduce significantly the micro-scratches observed with harder pads. Final polishing to obtain device grade surface was performed by a short cycle of sub-micron abrasives (0.50 to 0.03 micron diameter). Removal rates and surface roughness for various materials (with the new slurry) are quantified and compared with the conventional multi-step lapping and polishing schemes using alumina powder-water solutions. The high removal rates and superior surface finish are attributed to the agglomerate free suspension and the slurry chemistry.

E4.2
DEVELOPMENT OF TUNGSTEN CHEMICAL-MECHANICAL POLISHING PROCESSES USING A HYDROGEN PEROXIDE CONTAINING SLURRY. Liming Zhang, Milind Weling, Philips Semiconductors, San Jose, CA; Michele Cecchi, Francine Rios, Strasbaugh, San Luis Obispo, CA.

Recently, a commercial hydrogen peroxide containing slurry has gained a lot of interest for the tungsten chemical mechanical polishing (CMP) process. Of particular interest is the significantly improved defect performance of this slurry due to the absence of any metallic components in its composition and the use of silica as the abrasive. However, a known weakness with the use of hydrogen peroxide for tungsten CMP is its tendency to corrode tungsten. In this work, several variations of the tungsten CMP process using this hydrogen peroxide containing slurry were studied. The key differences in the process included multi-step vs. single step, and dilution of the slurry with deionized (DI) water vs. no slurry dilution. We will compare the performance of these CMP processes using criteria such as, process stability, tungsten removal rate and uniformity, pad temperature, and electrical tests, based on polishing unpatterned and patterned wafers.

E4.3
MULTI-LEVEL DAMASCENE PROCESS DEVELOPMENT: ALUMINUM CMP. David A. Hansen[a], Gerry Moloney[a] and Alex Reyes[a], Cybeq Nano Technologies, San Jose, CA. [a]Present Affilation: Multi Planar Technologies, Inc, San Jose, CA.

With the integration of advanced multi-level integrated circuit designs there is increased interest and efforts devoted to damascene-based processes. In addition, many IC manufacturers have decided to extend aluminum damascene technology into the manufacturing environment, which requires advanced Al CMP processes, and in turn the need to develop and integrate into the technology requirements of advanced ULSI circuits. Damascene technology, is essentially an in-laid metal process, which requires planarization of the first dielectric level. Once this dielectric is planarized using CMP, a trench is etched in the insulator material and subsequently filled with a conductive material such as W, Al, or Cu. CMP is then used to remove excess metal; thereby, defining the conductor. For an ideal multilevel aluminum damascene process, aluminum CMP would remove the entire aluminum over-layer with no dishing of the aluminum bond pads and electrical wiring with no oxide loss. In other words the plug and line height would be defined by the initial etch depth with no detects. Physically however the barrier material has a removal rate that differs from the aluminum material. This causes dishing of the bond pads and electrical lines. The extent to which this occurs is proportional to the local device dimensions and polishing non-uniformity. Hence the key CMP metrics to control the dishing and oxide erosion are the non-uniformity and the stop time or end pointing of the CMP process. However link to both the dishing and oxide erosion are the scratches imprinted due to the CMP planarization step. This due to the fact that large scratches require increases polishing times to remove the scratches. This paper focuses on characterizing the scratching of the aluminum material after Al-CMP processing with the objective of identifying the source of the scratches and methods used to minimize the source of scratches.

E4.4
EFFECT OF SLURRY CHEMISTRY ON REMOVAL RATES IN TUNGSTEN CMP. Dnyanesh Tamboli, Vimal Desai, Sudipta Seal, Cue Wei, Advanced Materials Processing and Analysis Center (AMPAC), University of Central Florida, Orlando, FL; Alvaro Maury, Bell Labs, Lucent Technologies, Orlando, FL.

Chemical mechanical polishing (CMP) is considered to be the enabling technology for meeting the planarization requirements in <0.35 micron feature sized multi-level devices and interconnects in semiconductor industries. Tungsten is widely used material for formation of vertical interconnects. In our previous studies we have shown that oxide formation and dissolution play a crucial role in removal of tungsten in CMP. Removal rates are found to be highest in the slurries, which have high rates for both tungsten oxidation as well as oxide dissolution. The corrosion potential of tungsten in slurries gives an indication of the oxidizing potency of slurry, whereas steady state passivation current density is a measure of oxide dissolution rate in slurry. In this study, we will attempt to incorporate these electrochemical parameters in the Preston relationship to take into account the effect of slurry chemistry on removal rates.

E4.5
PARTICULATE EFFECTS IN COPPER CMP. Seung-Mahn Lee, Uday Mahajan, Anupam Nagory and Rajiv K. Singh, Department of Materials Science and Engineering and Engineering Research Center for Particle Science and Technology, University of Florida, Gainesville, FL.

In this talk, the results of a study on the effect of abrasive properties on copper CMP are presented. Nanosized particles of different types and in the same size range, viz. SiO_2, Al_2O_3, CeO_2, ZrO_2 and TiO_2 were used for preparing the polishing slurries. The slurry chemistry consisted of 0.1 M KIO_3, 0.01 M KI and 0.001M EDTA at a pH of 6.5. The reasons for choosing this particular chemistry have been explained in another talk. The particle concentration was maintained constant at 2 vol.%. The polish rate and surface morphology of the samples was correlated to the abrasive properties (density, hardness, charge etc.). These results can help obtain a better understanding of the mechanical effects of the abrasive particles in copper CMP.

E4.6
OPTIMIZATION OF PAD CONDITIONING ON AVANT GAARD 676/776. Sumit Guha Nikolay Korovin, John Herb, Sandeep Koppikar, Yakov Ephstein, Steve Schultz and Ajoy Zutshi[a], SPEEDFAM-IPEC, AZ. [a]currently@ Applied Materials.

The standard pad conditioner on the AvantGaard 676/776 is an elongated bladder with an attached diamond abrasive strip; the bladder is pressurized to 2.0-3.0psi as it sweeps across the surface of the pad between each polish cycle. This configuration results in non-uniform pad conditioning with excessive non-uniform pad wear which typically limits the life of the pad. An advanced pad conditioner (termed APC) has been developed which replaces the pressurized bladder with a passive element (a foam support). Another enhanced pad conditioning feature namely APM has been added to AvantGaard 676/776 wherein, the pad is rotated during conditioning. This helps to minimize unconditioned spots at the edge of the pad. APM and APC combined have been demonstrated to reduce the pad cut rate and erode the pad evenly. In implementing APM and APC as the next generation pad conditioner of choice, the interactions between three motions: the orbital motion of the polish head, the angular sweep of the pad conditioner and the rotational motion of the pad with APM, had to be modeled. A kinematic model for the pad conditioner was developed to understand these interactions, and to help optimize pad conditioning with respect to five parameters: the pad conditioner sweep angle and speed, the APM range and speed, and orbital speed. Pad erosion uniformity was optimized numerically by varying these five parameters within the mathematical model, and model predictions were validated experimentally. This paper will describe the kinematic pad conditioner model and present data validating the model predictions. The end result is a pad conditioning technique that eliminates any non-uniform erosion of the pad, which is beneficial to pad life and stability of CMP processes.

SESSION E5: POSTER SESSION: PROCESS INTEGRATION AND MANUFACTURABILITY

Wednesday Evening, April 26, 2000
8:00 PM
Salon 1-7 (Marriott)

E5.1
IMPROVEMENT OF WAFER EDGE PROFILE AND CMP PROCESS PERFORMANCE THROUGH THE FLOATING HEAD DESIGN. Huey-Ming Wang, Gerry Moloney, Mario Stella, Sesinando DeGuzman, Cybeq Nano Technologies, San Jose, CA.

The dependence of IC fabrication on the Chemical Mechanical Planarization (CMP) process increases as the device features go down to 0.25 micron or beyond. Due to the tighter CMP process spec, it is very important to reduce the within wafer non-uniformity (WIWNU%) at small edge exclusion to achieve higher process yield. The improvement of the CMP process performance might go through the modification of either the polisher design, the consumable sets, or both. The better solution is through the change of head design for a fixed platen from the polisher design point of view.
This study demonstrates the improvement of the CMP process performance, especially at the wafer edge, from the modification of the floating type polish head. The symmetrical increment of linear velocity at wafer edge is not sufficient to change wafer edge profile by breaking the matched speed rule. The best WIWNU% from this head is about 5.12% at 6-mm edge exclusion (EE)from single pressure chamber head. In order to obtain better pad deformation control, the retaining-ring pressure chamber is separated from that of the sub-carrier. The average WIWNU% is about 4% for 3-mm and 5-mm EE from two-pressure-chamber head. Due to the limitation of retaining-ring pressure effect, a third pressure chamber is further added to control the wafer edge profile that is extended up to 1 inch from the wafer edge. The WIWNU% is about 3.8% at 5-mm edge exclusion with low down forces. The slurry and insert types also show effect on the wafer edge profile. It has been also proven that this three-pressure-chamber head is able to reduce the post-CMP thickness variation from the ILD production wafer, especially at wafer edges. More detailed information and CMP mechanism will be discussed in this paper.

E5.2
ENGINEERING THE POLISH SELECTIVITY BETWEEN OXIDE AND NITRIDE DURING CHEMICAL-MECHANICAL POLISH. Ping-Lin Kuo, Dept of Chemical Eng., Wei-Tsu Tseng, Rick Lu, Dept of Materials Sci. & Eng., Chin-Lung Liao, Dept of Chemical Engr., and Jen-Fin Lin, Dept of Mechanical Eng., National Cheng-Kung University, Tainan, TAIWAN.

Polish selectivity between oxide and nitride has been a critical issue for the application of chemical-mechanical polish (CMP) to ULSI manufacturing process. For example, a high oxide/nitride polish selectivity is usually required for the nitride layer to serve as an effective polish stop during CMP for shallow trench isolation. Control of this polish selectivity issue is not an easy task, since the large differences and variations in chemical and mechanical characteristics between oxides and nitrides result in disparate hydration and abrasion rates during polishing. In addition, the pattern density effects and the uneven partition of pressure among local features of different width exacerbate the problem. Results from our preliminary work indicated that the addition of only finite amount of surfactant and wetting agents into the conventional silica-based alkaline slurries brought about a significant change in oxide removal rates. While for nitrides, such a tendency is less obvious. This provides a key for engineering the polish selectivity. This change in removal rates due to variation in slurry chemical content was also reflected in frictional force measurements, which serve as a potential method for monitoring the polish selectivity. In the present work, silicon-based and organic-based surfactants and wetting agents will be added to conventional silica-based oxide slurry for the fine-tuning of oxide and nitride polish rates. A test structure with varying pattern density mimicking the case of STI will be used for polishing with the slurries formulated. Frictional force measurements will be conducted to detect the variation in frictional force with time for the better control of polish stop employing nitride layer. Surface analysis adopting AFM and ESCA will be performed to characterize any change in surface properties during polish with the surfactant-added slurries. The results would not only serve as a guideline for engineering the polish selectivity, but also help clarify the basic polish mechanisms involved during oxide and nitride CMP.

E5.3
A NEW POLY-Si CMP PROCESS WITH SMALL EROSION FOR ADVANCED TRENCH ISOLATION PROCESS. Naoto Miyashita, Meiji Univ, Dept of Electrical and Electronic Engineering, Toshiba Co, Semiconductor Company, Yokohama, JAPAN; Shin-ichiro Uekusa, Meiji Univ, Dept of Electrical and Elecronic Engineering, Kawasaki, JAPAN; Takeshi Nishioka, Satoko Iwami, Toshiba Co, Corporate R&D Center, Kawasaki, JAPAN.

Chemical-Mechanical Polishing has been revealed as an attractive technique for poly-Si of trench planalization. Major issue of the process integration is pattern erosion after over polishing. A new process with silica slurry containing organic surfactant is reported in this paper. A patterned wafer after conventional CMP process is eroded by over polishing, however, the new process conducts small erosion for wide trenches. The organic surfactant is well known as a inhibitor for the protection of poly-Si from alkaline, and the new slurry shows a large pH dependency of the viscosity. The experimental work has been focused on the viscosity, and the mechanism of the small erosion is discussed. This new process should be useful for recessing poly-Si by CMP, because it keeps the erosion level very low.

E5.4
THE CHARACTERISTICS OF THE ELECTROLYZED WATER WITH CHEMICALS AND THE OUTLINE OF THE SUPPLY SYSTEM. Mitsuhiko Shirakashi, Kenya Itoh, Ichiro Katakabe, Ebara Corporation, Precision Machinary Group, Kanagawa, JAPAN; Takayuki Saitoh, Kaoru Yamada, Ebara Reserch Ltd, Center of Technology Development, Kanagawa, JAPAN; Naoto Miyashita, Masako Kodera, Yoshitaka Matsui, Toshiba Corporation Semiconductor Company, Manufacturing Engineering Center, Kanagawa, JAPAN.

In the semiconductor manufacturing process, wafers have to go through many cleaning processes. Usually, each cleaning step uses different mixed chemicals, such as RCA method, and the cleaning process steps are set up in an order to have the required cleaning performance. As wafer size becomes larger, large amount of chemical usage is necessary, which requires higher capacity of the waste chemical treatment system. Considering the above, we developed the supply system of ultra-clean electrolyzed water for the purpose of reducing a load of the waste chemical treatment system, and the decreasing the running cost. It is feature that; 1) this system can generate the anode water of the acidity/high ORP and the cathode water of the alkalinity/low ORP by electrolyzing ultra-pure water adding with a small quantity of chemicals; 2) this system can generate anode water and cathode water at the same time or separately; 3) if necessary, the anode water can be diluted with DI water at the optional density, and it is possible with the cathode water that hydrogen peroxide is added. The anode water which shows acidity/ high ORP has the effect of cleaning metal and organic contamination, and the cathode water which shows alkalinity/low ORP has the effect of particle removal. In this paper, we report the outline of ultra-clean electrolyzed water supply system and the basic characteristic of the water made with this system.

E5.5
POST CMP CLEANING: CHALLENGES BEYOND BLANKET WAFER DEFECTS. Brian Fraser and Michael B. Olesen, VERTEQ, Inc, Santa Ana, CA.

Currently, the most common benchmark for post CMP cleaning efficiency is the number of defects on blanket wafers as measured by laser scanner tools (typically Tencor 6420). However, as CMP matures, more specific post CMP cleaning challenges have been investigated and reported. Defect categories to be discussed include the following: (1) blanket wafer defects not analyzed effectively by laser scanners, (2) defects specific to patterned wafers, (3) defects not on the wafer frontside and (4) defects on metals. Blanket wafer defects (category 1) include microscratches, low aspect ratio defects and defects on polycrystalline Si. Defects resulting from topography on the die (dished and recessed areas) and outside the die (scribe and alignment marks) will also be discussed. Defects which do not show during frontside inspection (edge bevel and backside defects) have been shown to create problems in subsequent processes. The final category to be discussed is defects on metal surfaces, both on W plugs and on Cu lines. The impact of the cleaning method on removing the different types of defects will be presented. The cleaning method discussion will include the two primary types of cleaning tools (PVA brush scrubbers and megasonics) as well as the cleaning chemistry.

E5.6
OPTIMIZED DIRECT POLISH OF STI FOR THE SUB 0.25 MICRON ERA. Peter McKeever, Benjamin A. Bonner, Jeffrey David, Tom Osterheld, Applied Materials, CMP Division, Santa Clara, CA.

The semiconductor industry continues to validate Moore's Law by fitting more and more transistors on each individual die. In order to achieve the smaller and smaller line widths required, manufacturing techniques must be constantly improved, replaced or invented. Chemical mechanical polishing (CMP) is the latest processing technique to be incorporated in the manufacture of integrated circuits as the industry adopts sub 0.25 micron technology. CMP is currently the production method of choice to planarize pre-metal dielectric and inter-level dielectric layers. The necessity to integrate shallow trench isolation (STI) with sub 0.25 micron technology has led to another application for oxide CMP. Current manufacturing processes use reverse etch or dummy features to achieve satisfactory STI polishing performance. This adds steps or complexity that have significant cost or performance implications. For these reasons a direct polish STI process represents the next step in the evolution of STI polishing. This paper outlines the methodology used to quantify dishing, die range, step-height reduction, and nitride loss as a function of polish time and in particular, over-polish time. The results were derived from 200mm wafers patterned with a modified version of the MIT mask and having a full STI stack. These wafers were deposited with both HDP and PETEOS oxide films. Results will be presented for over-polish ranging between 0 and 50%. Among the parameters studied were polish pressure, type of oxide film, type of conditioning disk, type of polishing pad and type of slurry. Optical in-situ traces of film removal are used as a metric for monitoring polishing process and developing a precise endpoint.

E5.7
INTEGRATION OF POROUS LOW-K MATERIALS WITH COPPER INTERCONNECT: CMP AND OTHER PROCESS INTEGRATION ISSUES. Stan Tsai, Robert Mandal, Kapila Wijekoon, Rajeev Bajaj, Sure Ngo, Fritz Redeker, Applied Materials, Santa Clara, CA.

In fabrication of an ultra-large-scale-integrated (ULSI) circuit, it is essentially required for high performance to have copper interconnect with low-k dielectric materials. A wide range of organic and inorganic materials are being developed as potential low-k materials ($k<3$), among which, porous low-k materials attract high interest in the industry due to their exceptionally low dielectric constant ($k<2.5$). This paper summarizes a program to integrate a porous low-k material with copper interconnect. A wide range of process integration issues, especially those related to chemical mechanical polish in copper slurries, including the mechanical strength of the material, the choice of the cap material and the use of sacrificed PETEOS. While cap loss is largely driven by local de-adhesion issues for blanket films, cap loss in patterned wafers is highly pattern density and tile area dependent. Requirements for a Porous low K friendly copper CMP process wrt post-CMP topography, surface defectivity, are discussed.

E5.8
EFFECTS OF ABRASIVE AND WETTING AGENT IN THE SLURRY ON CHEMICAL MECHANICAL POLISHING OF LOW DIELECTRIC CONSTANT FILMS. H.H. Lu, L.M. Chen, Shen-Nan Lee, Y.T. Chen and D. Liu, Union Chemical Laboratories, Industrial Technology Research Institute, Hsinchu, TAIWAN ROC.

Low dielectric constant (low k) materials received extensive attention owing to their applications as an interlayer dielectric in 0.18 μm

CMOS structure. Using such materials in current IC fabrication schemes necessitates the development of reliable chemical mechanical planarization (CMP) process for low k materials. This work performs CMP experiments on HSQ and fluorinated polyimide with a variety of abrasive slurries derived from colloidal silica, fumed silica, and alumina, respectively. The experimental results indicate that basic slurries, such as colloidal silica based slurry and fumed silica based slurry, have a higher removal rate of HSQ than that of acidic alumina based slurry. This finding suggests that the hydrolysis reaction controls the removal rate of HSQ even its high hydrophobic surface. On the other hand, although it is extremely difficult for basic slurries to remove fluornated polyimide, acidic slurry can be used to remove it. This occurrence is attributed to acidic corrosion on the surface of fluornated polyimide. Experimental results further demonstrate that adding wetting agent into slurries can modify the surface of fluornated polyimide from hydrophobic to hydrophilic to enhance the removal rate of fluornated polyimide.

SESSION E6: POSTER SESSION: CMP CONSUMABLES

Wednesday Evening, April 26, 2000
8:00 PM
Salon 1-7 (Marriott)

E6.1

AN IMAGE ANALYSIS TECHNIQUE FOR ASSESSING PARTICLE SIZE AND AGGLOMERATION TENDENCY OF SLURRIES. Susan Machinski, Univ of Central FL, Dept of Chemistry, Orlando, FL; Kathleen Richardson, Univ of Central FL, School of Optics, Orlando, FL; Aristide Dogariu, Univ of Central FL, School of Optics, Orlando, FL.

Understanding the time-dependent behavior and size of particulate systems, specifically, particles in abrasive slurries, is a key part of chemical mechanical polishing (CMP). Traditional electrochemical techniques correlated with optical signals from laser light back-scattering techniques have been used previously for investigating particle size and stability. However, electrochemical techniques required dilution of the slurry system and laser light back-scattering does not. Thus a quantitative measure of particle size and distribution as a function of slurry concentration, as a function of slurry age, was sought. Microscopy and image analysis enables both qualitative analysis and quantitative analysis of particle interaction behavior interaction as a function of time and chemical environment in diluted samples of such particulate suspensions. A technique using microscopy and image analysis has been developed specific to the analysis of suspensions of, micron size or larger, abrasive particle slurry systems. This technique has been applied to Al_2O_3 slurries and measurements of particle size and stability have been obtained with good accuracy and precision. The pH for different concentrations of the slurry was observed to increase with increasing concentration and, with the exception of the lowest concentration, remained stable for each individual concentration during the length of this study. Examination of "stabilized" Al_2O_3 slurries over a two week period showed no appreciable change in measured most frequent area for different concentrations of this slurry but it did show a decrease in the average area. The normalized particle size distribution did not show representation that a large increase in particle size occurred.

E6.2

INVESTIGATION OF MATERIALS FOR CHEMICAL MECHANICAL PLANARIZATION CARRIER WEAR RINGS. Wayne Lougher and Tim Dyer, SpeedFam-IPEC Corporation, Chandler, AZ.

Corrosion resistant polymeric materials such as acetal homopolymer, acetal copolymer, and more recently polyphenylene sulfide (PPS) have been used in Chemical Mechanical Planarization (CMP) wafer carrier retaining ring applications. In this paper, a variety of materials are evaluated for consideration as wafer retaining rings for CMP carriers. Materials such as polymers, composites, and ceramics were evaluated for wear rates. Wear rate testing was conducted on an actual CMP polisher with fumed silica slurry. The ceramic materials displayed the lowest wear rates as expected and the wear rate scaled generally with the hardness. Microstructures of the ceramic materials are presented and discussed relative to their application in CMP. Relative costs of ownership for the different materials are presented.

E6.3

OPTIMISATION AND EVALUATION OF NEW POLISHING SOLUTIONS FOR GALLIUM ARSENIDE (GaAs) AND INDIUM PHOSPHIDE (InP) SINGLE CRYSTALS. M. Udhayasankar, R.R. Sumathi, J. Kumar and P. Ramasamy, Crystal Growth Centre, Anna University, Chennai Madras, INDIA; K. Sankaranarayanan, Crystal Research Centre, Algappa University, Karaikudi, INDIA.

Chemo-mechanical polishing (CMP) has been recognised as an important and critical step that requires in almost every device fabrication process. Many different defects are introduced in a layer beneath the wafer surface during polishing and change in the electrical and optical properties was observed in these damaged layer. Hence, the polishing method used for preparation should guarantee the stringent requirements for device applications. High quality surfaces (damage free) are essential requirements not only for the fabrication of devices but also for most of characterisation studies that are employed for revealing and evaluating crystallographic, compositional inhomogeneities. We report in this work, realisation and optimisation of new polishing solutions namely aqueous ammonia-H_2O_2 solutions with SiO_2 slurry for GaAs and a mixture of HBr-$K_2Cr_2O_7$-H_2O solutions for InP. All samples used in this study were grown at our centre by liquid encapsulated Czochralski technique and polishing has been performed by CMP method. For GaAs, the wafers were polished by varying different polishing parameters such as rotation rate of polishing pad, the sample holder, flow rate of the solution/or slurry and pH of the solution. Finally the proper polishing condition was optimised. Microscopic analysis of the prepared surfaces shows that the polished surfaces are of very high quality without any sub-surface damages. The effect of addition of slurry has also been investigated. The assessment of the polished wafers by photo-luminescence and atomic force microscopy measurements will be presented. For InP, the polishing has been carried out by varying composition of the solutions and proper composition (221) was evaluated. In this optimised composition region, the solution is well diffusion controlled and has a very good polishing action resulting in good quality surfaces. The chemical mechanism of the polishing action and the results of microscopic analysis will be further discussed.

E6.4

MONITORING THE EFFECTS OF HARD AND SOFT AGGLOMERATES IN CMP SLURRIES ON POLISHING PERFORMANCE. G. Bahar Basim, J. Joshua Adler, Uday Mahajan, Brij M. Moudgil, University of Florida, Dept of Materials Science and Engineering and Engineering, Research Center for Particle Science and Technology, Gainesville, FL.

The continually decreasing size of microelectronics devices requires close and effective control of the abrasive particle size distribution in chemical mechanical polishing (CMP) slurries. In previous work, a small concentration of coarser particles in the slurry has been shown to create microscratches or pit formation on wafer surfaces, depending on the coarseness of the oversized particles, which could result in defective microprocessors. In the current investigation, the performance of silica CMP slurries was evaluated in the presence of hard and soft agglomerates that may form during polishing. Slurry performance was quantified in terms of material removal rate, surface damages and surface roughness. It was determined that hard aggregates significantly degraded slurry performance even at ppm concentration levels. Effects of soft agglomerates in CMP slurry were also investigated to assess the importance of slurry stability. The changes in the particle size distribution due to aggregation were monitored before and after the polishing process using light scattering technique. The performance of the slurries was found to be closely related to the interparticle forces encountered during slurry formulation.

E6.5

WAFER POLISHING PERFORMANCE OF SILICA SLURRIES WITH SILICA PARTICLES GROWN BY SOL-GEL METHOD. Sun Hyuk Bae, Jae-Hyun So, Seung-Man Yang and Do Hyun Kim, KAIST, Dept of Chemical Engineering, Taejon, KOREA.

In the manufacturing of silicon wafer, wafer is polished after slicing step to remove surface damage resulted from slicing operation and to maintain uniform wafer thickness and smooth wafer surface. Silica slurry is fabricated by dispersing 20-200 nm size of silica particles in a high-purity alkali solution to be used as a polishing abrasive in wafer polishing process. Although various commercial silica particles such as colloidal silica and fumed silica have been adopted as abrasives in wafer polishing process, there still exist some modifications in wafer polishing silica slurry. Colloidal silica like commercial Ludox has small diameter and metal ions such as Na^+ or K^+ added for stabilization and fumed silica particles have too broad size distribution and irregular shapes. Therefore, in this study silica particles were prepared by stepwise growth of fumed silica or colloidal silica particles as seeds by sol-gel method. We have grown silica particles by hydrolysis and condensation of silicon precursor within basic alcohol/water mixture using pre-treated fumed or colloidal silica particles as seeds. After growth step, alcohol-base solvent was substituted with water and additives were added to accelerate a polishing rate. Moreover, the silica slurry was stabilized both electrostatically and sterically by adjusting pH and adsorption with non-ionic surfactants. Prepared slurries were tested using one-armed polisher to compare with

commercial slurry, Nalco2371 which is commonly used for stock removal polishing in wafer industry. Prepared slurries showed comparable performance to commercial slurry in terms of removal rate and surface roughness.

E6.6
ROLE OF INHIBITORS IN PRESENCE OF OXIDIZERS IN Cu-CMP. D. Tamboli, S. Seal, J. Ramsdell, V. Desai, Advanced Materials Processing & Analysis Center (AMPAC) and Mechanical, Materials and Aerospace Engineering (MMAE), University of Central Florida, Orlando, FL.

The current USLI technology is continued to be driven towards miniaturization (< 0.1 micron) of integrated circuits. CMP has emerged to be the key technology for feature sizes of 0.35 micron and below to meet the stringent requirements for next generation microelectronic devices. Cu CMP is the technology for producing submicron Cu line in multilevel metallization as the line widths are getting smaller and smaller. During Cu CMP, understanding of surface oxidation, dissolution and modification is important to put forward a mechanism for materials removal. Slurries containing oxidizers and inhibitors play an important role in material removal and subsequent Cu surface chemistry. While electrochemical measurements are performed to determine corrosion rate, degree of surface passivation and dissolution, detailed surface chemistry is carried out using XPS and AES techniques. Formation of Cu-complexation in slurries containing H_2O_2 and KIO_3 with or without BTA plays an important role in both polish and etch rates. Special emphasis is focused on monitoring changes in copper oxide/hydroxides stoichiometry.

E6.7
INFLUENCE OF MICROSTRUCTURE OF POLISHING PADS ON PLANARIZATION: A NUMERICAL APPROACH. Hong Liang, J. Lee, T. Zhang, J. Xiao, University of Alaska Fairbanks, Department of Mechanical Engineering, AK.

Our previous results indicated that the microstructure (open- and closed cells) of the polishing pads can have a profound effect on their mechanical behavior and polishing performance. In this work, we investigated the behavior of an entire polishing pad made up of multiple unit cells. We have found that the unevenly distributed applied pressure, present during polishing due to frictional force and rotating motion, has a significant influence on the elastic and plastic behavior of the pad crossing the wafer. The stress distribution, pad's mechanical behavior and performance depend on the microstructure of the pads. This presentation will illustrate our finding and discuss the relationship between the microstructure of the pads, the applied pressure, and their influence on planarization.

E6.8
SLURRY STABILITY AND FILTRATION EFFECTS OF CHEMICAL MECHANICAL POLISHING SLURRIES.
Rhonda Ewasiuk, Seungkwan Hong, Vimalkumar Desai, AMPAC, University of Central Florida, Orlando, FL; John Maze, Charles Storey, William Easter, Lucent Technologies, Orlando, FL.

Characterization and stability of two common CMP slurries were evaluated fundamentally and under processing conditions. Aggregation of the slurry particles was attempted by increasing the salt concentration of the solution, altering the pH, diluting the slurry, and inducing shear. Particle size, particle size distribution, pH, conductivity, and zeta potential (electrophoretic mobility) of the slurry particles were monitored over time during each set of experiments. The stability and polishing behavior of the slurries was then evaluated under filtration using polypropylene depth filters. These filters are designed for the CMP industry to remove particle aggregates formed in the slurries. Slurry aggregates are believed to cause detrimental scratches across the surfaces of the wafers during polishing. Both recirculating and point of use filters were tested at Lucent's facility in Orlando, Florida on blanket wafers, with a standard STI polishing recipe. Complimentary slurry testing was also performed on an experimental scaled-down version of Lucent's slurry loop at the University of Central Florida. The testing at UCF allowed for more flexibility in the processing variables and different dilutions, oxidizer concentrations, flow rates and agitation rates were evaluated for several POU and global filters.

E6.9
CHARACTERIZATION OF POLISHING PADS BY A LOW-COHERENCE OPTICAL TECHNIQUE. Lorrene Denney, Claudia Mujat, Aristide Dogariu, School of Optics/CREOL, Univ. of Central Florida, FL.

Chemical mechanical polishing (CMP) is a tribochemical process used in the planarization of silicon wafers by the concurrent interaction of a polishing pad, a slurry, and a semiconductor wafer. The rough surface texture of the polyurethane polishing pads is ideal due to the material's hardness and elasticity, which help maintain performance under the pressure required by the CMP process. Understanding the effects of pressure on porous media and other characteristics of polyurethane polishing pads during the polishing process is important to the further development of CMP technology, particularly in pad development and usage. In this paper, we show that characteristics of porous media can be determined using the technique of optical pathlength spectroscopy (OPS) that we have recently introduced. Through this noninvasive technique, changes in optical properties at and beyond the surface including changes in the thickness of the polishing pads are observed with varying static and dynamic loads. We developed the methodology and the phenomenological understanding that relate the optically accessible information to the structured modifications in CMP polishing pads. The differences in optical properties have also prospective importance in understanding the plastic deformation and wear mechanisms in polishing pads.

E6.10
OPTICAL CHARACTERIZATION OF POROUS MEMBRANES. Claudia Mujat, Lorrene Denney, Aristide Dogariu, School of Optics/CREOL, Univ. of Central Florida, Orlando, FL.

Multiple light scattering techniques are intensively investigated as potential characterization tools for a broad range of applications. We are reporting on the noninvasive characterization of filters used in processes such as slurries filtering for CMP. Filters are soft porous membranes characterized by their pore size distribution and thickness, and a noncontact, nondestructive optical procedure to measure these properties is highly desirable. Due to their internal inhomogeneity, porous media strongly scatter light and, therefore, a specific procedure needs to be developed. In this work, low coherence interferometry is used to investigate light propagation in the filter and obtain the reflectivity as a function of optical pathlength for backscattered photons. This can be subsequently related to the optical properties of the sample using analytical and/or numerical models, and the porosity of the sample can be determined. In the case of filters with thicknesses much larger than the wavelength, a diffusion approximation for light propagation is used to infer the porosity information. For thinner membranes, numerical methods are used to describe the intermediate low-scattering regime that can not be represented analytically. As a direct result of the measurement, the thickness of the filter is determined independent of porosity.

SESSION E7: CMP CONSUMABLES
Chair: Rajiv K. Singh
Thursday Morning, April 27, 2000
Salon 10/11 (Marriott)

8:30 AM *E7.1
INTERFACIAL PRESSURE MEASUREMENTS AT THE PAD/SILICON INTERFACE. Lei Shan, Steven Danyluk, Georgia Institute of Technology, George W. Woodruff School of Mechanical Engineering, Atlanta, GA; John Tichy, Mechanical and Aerospace Engineering Department, Rensselear Polytechnic Institute, Troy, NY.

Interfacial pressures have been measured at a pad/fixture interface sliding over a polishing platen. The fixture is not rotated during sliding. The speeds of sliding and loads on the fixture are in the range of 0-20m/s and 0-20kPa respectively. The fixture geometry is flexible so that a dome shape (amplitude of approximately 100 microns) can be purposely imposed on the 100mm diameter surface. Subambient and positive pressures have been measured during sliding depending on the dome amplitude. The model that predicts the pressures will be described.

9:00 AM E7.2
MEASUREMENT OF CHEMICAL AND MECHANICAL INTERACTIONS OF ABRASIVES AND SURFACES IN CMP AND POST-CMP CLEANING. Joshua J. Adler, Bahar Basim, Yakov I. Rabinovich, Brij M. Moudgil, University of Florida, Engineering Research Center for Particle Science and Technology and Department of Materials Science and Engineering, Gainesville, FL.

During chemical mechanical polishing (CMP), an abrasive particle is pressed against the surface at forces that are at least an order of magnitude greater than commonly experienced in colloidal suspensions. Under these high forces, the separation distance between surfaces becomes small (less than 1 nm) and mechanical as well as chemical processes govern the interaction during the CMP process. Description of this interaction is critical to the determination of polishing mechanisms and removal of particles during post-CMP cleaning. However, few predictive models of colloidal interactions are valid in solutions containing oxidizers, dispersants, or other reagents, especially in a high force environment. Additionally, mechanical interactions are often difficult to predict because physical parameters such as hardness and morphology of thin surface layers under chemical attack are often difficult to determine. Standard methods to measure interactions between surfaces, such as the surface force apparatus (SFA) and atomic force microscope (AFM) can apply pressures equivalent to those during CMP, but because of the large gradient of the repulsive force, differences between conditions are difficult to resolve. To elucidate some of the mechanisms of polishing, micro-tribological experiments between a colloid probe (abrasive) and CMP substrate (silica, tungsten, copper) were performed using AFM. In oxidation based polishing, material is quickly removed from the surface after oxidation occurs. To simulate these conditions and prevent a thick layer of oxide from forming, an electrochemical cell was used to control the state of the metal surfaces. To determine the effectiveness of dispersants and post-CMP cleaning methods, the adhesion force was also measured using AFM after applying equivalent pressures to those in CMP.

9:15 AM E7.3
MECHANISTIC ASPECTS OF THE RELATIONSHIP BETWEEN CMP CONSUMABLES AND POLISHING CHARACTERISTICS.
Irene Li, Kersten M. Forsthoefel, Kathleen A. Richardson, School of Optics/CREOL, Department of Chemistry, University of Central Florida, Orlando, FL; Yaw S. Obeng, William G. Easter, Alvaro Maury, Bell Laboratories, Lucent Technologies, Orlando, FL.

There is an emerging need to establish fundamental, mechanism-based, correlation(s) between process conditions, consumables (e.g., pads and slurries) and observed process performance in chemical-mechanical polishing (CMP). In this paper, we discuss some of these fundamental relationships, and present recent results of studies performed on pads, slurries and their interaction. Specifically, this paper will address the interaction between the polyurethane-based pads (IC1000, Suba IV, IC1000/Suba IV) and some commercial slurries (MSW 2000, Klebosol 1498, Klebosol 1501). The corresponding variation in pad hardness, absorption, morphology, microstructure and mechanical integrity in various pH (slurry chemistry) and organic (DMF, DMSO) environments were used to identify a model of interaction.
The extent of fluid absorption and hardness changes were found to be pH dependent, with basic conditions exhibiting the most drastic effect. After subsequent testing in organic solvents it was observed that upon exposure to a chemical environment, the solvent wets, penetrates and swells the polyurethane matrix. Once inside, the solvent or any other dissolved nucleophilic species (e.g., OH-) can attack the carbonyl center (-NC(O)O-) of the urethane structure, effectively destabilizing the polymer structure and altering its mechanical properties. By compromising the properties of the pad matrix, parameters such as removal rates, within wafer non-uniformity, and defectivity, are significantly affected. These parameters are heavily influenced by the chemistry of consumables and their progressive interaction with the slurry environment during the CMP process.

9:30 AM E7.4
AN EVALUATION ON THE EFFECTS OF BENZOTRIAZOLE IN NH_4 OH SLURRY FOR COPPER CMP.
Vee S.C. Len, David W. McNeill, Harold S. Gamble, Queen's University of Belfast, Dept of Electrical and Electronic Engineering, Belfast, NORTHERN IRELAND.

Chemical mechanical polishing (CMP) of copper (Cu) metallisation using Benzotriazole (BTA) containing NH_4 OH slurry has been evaluated in terms of polish efficiency. Chemical dissolution and continual mechanical abrasions due to the deformed pad bending into the Cu recess regions result in a serious dishing phenomenon, i.e. thinning of the Cu lines. The formation of a thin Cu(I)-BTA polymer over the recessed Cu proves to be an effective method of protecting the Cu from chemical dissolution and minimises mechanical abrasion, and hence dishing is significantly reduced by a factor of 8. Cu polish rates in BTA containing slurry are generally lower than that without BTA. It was found that the polish rate decreases with increasing BTA concentrations in the slurry; but saturates when BTA concentration exceeds 0.25 wt.%. AFM studies showed that the grainy as-deposited Cu surface was smoothened out after subsequent CMP processes. Cu electromigration resistance test structures have been successfully patterned using a 2-steps CMP and etching scheme.

10:15 AM *E7.5
MEASUREMENTS OF SLURRY FILM THICKNESS AND MIXING DURING CHEMICAL MECHANICAL PLANARIZATION.
Ara Philipossian[1], Jonathan Coppeta[2], Joseph Lu[2], Mansour Moinpour[1], Chris Rogers[2], Livia Racz[2] and Frank Kaufman[3]. [1]Intel Corporation, Fab Materials Operation, Santa Clara, CA, [2]Tufts University, Department of Mechanical Engineering, Medford, MA, [3]Cabot Corporation, Microelectronics Materials Division, Aurora, IL.

Using dual emission laser induced fluorescence (DELIF) we are able to non intrusively measure the slurry film thickness underneath the wafer, slurry transport and slurry mixing during real time polishing conditions. In addition, this same technique can be used to measure temperature and pH gradients during polishing. Using laser induced fluorescence, a design of experiment was conducted to show the interdependencies of polishing parameters such as platen speed, flow rate, down force, conditioning, pad type, and pad manufacturer and how this effected slurry transport and slurry mixing. With a Dektak 200-Si profilometer we are able to study the effects of pad topography on polishing uniformity. So far our experiments indicate polishing rates of 1000 to 2000 Angstroms per minute depending on the type of substrate being polished. Over the years we have been able to identify some key factors involved in determining the efficiency of the CMP process, including wafer shape, pad topography, friction, slurry film thickness, and pressure distribution underneath the wafer. Currently, we are looking at the effect of wafer shape on friction, slurry film thickness, pressure distribution, and polishing uniformity. Our experimental results have agreed with numerical simulations done concurrently.

10:45 AM E7.6
PAD SURFACE CHEMISTRY IN CHEMICAL MECHANICAL PROCESS.
S. Seal, Advanced Materials Processing & Analysis Center (AMPAC) and Mechanical, Materials and Aerospace Engineering (MMAE); I. Li, K.A. Richardson, School of Optics, University of Central Florida, Orlando, FL; B. Easter, Bell Laboratories, Lucent Technologies, Orlando, FL.

Chemical mechanical polishing involves various basis consumables such as abrasives, pads, slurries, etc. The process is very dynamic and thus a thorough understanding of the mechanistic aspects of the various CMP consumables interaction is required. CMP pads are primarily polyeurathane based materials. This paper reports the application of X-ray photoelectron spectroscopy to map the pad surface chemistry as a function of slurry chemistry, pH and other organic medium. This technique allows us a nondestructive evaluation of the pad materials providing both elemental and chemical state information. Furthermore AFM is used to track the topographic variation of pads and are correlated to removal rates, within wafer nonuniformity and other CMP parameters. (The work is supported by Lucent Technologies)

11:00 AM E7.7
IN-SITU FRICTION FORCE MEASUREMENTS IN CMP.
Uday Mahajan, Seung-Mahn Lee and Rajiv K. Singh, Department of Materials Science and Engineering and Engineering Research Center for Particle Science and Technology, University of Florida, Gainesville, FL.

In this talk, we present results obtained using a novel in-situ friction force measurement technique developed by us. In-situ measurements can provide valuable information about process fundamentals and are useful tools for process monitoring as well. In previous work, we have shown that friction force measurements are sensitive to surface roughness, as well as the solution chemistry used during the measurements. In this study, a modified version of the same apparatus has been used, which has the capability to rotate while the measurements are being carried out. This allows us to simulate actual process conditions more accurately. Using this setup, we have obtained results showing that this technique is sensitive to changes in pad conditions, as well as to the roughness changes of the wafer during metal and oxide CMP. Based on these and future experiments, we hope to obtain a much better understanding of CMP process mechanisms and develop this technique for online process monitoring, especially for pad degradation measurements.

11:15 AM E7.8
FUNDAMENTAL STUDIES ON IODATE SLURRY CHEMISTRIES DURING CHEMICAL MECHANICAL POLISHING (CMP) OF COPPER.
Seung-Mahn Lee, Uday Mahajan, Anupam Nagory, Zhan Chen, Valentin Craciun and Rajiv K. Singh, Department of Materials Science and Engineering and Engineering, Research Center for Particle Science and Technology, University of Florida, Gainesville, FL.

We have investigated new slurry chemistries for chemical mechanical polishing of copper to obtain high removal rate, good planarity, and relatively high selectivity over SiO_2 using intermediate pH slurries. They are based on forming a protective passive layer on the copper surface with Benzotriazole (BTA) and potassium iodide (KI) and enhancing the dissolution rate of copper in the slurries with a complexing agent, ethylenediamine tetraacetic acid (EDTA), in slurries containing potassium iodate (KIO_3) oxidizer. The characteristics of these slurry chemistries have been investigated by electrochemical measurements (potentiodynamic polarization measurements), inductively coupled plasma-atomic emission spectroscopy (ICP-AES) measurements, and x-ray photoelectron spectroscopy (XPS), and then chemical mechanical polishing of copper has been conducted with these slurry chemistries. From the experimental results, it was observed that BTA are effective in forming Cu-BTA passive layers in the pH range 4~6. The slurries with KI can form the CuI compound passive layers on the copper surface. Additional EDTA enhanced the polishing rate due to increased dissolution rate of abraded copper particles. Therefore, slurries with BTA and EDTA or with KI and EDTA are shown optimized CMP condition: relatively high removal rate, low R_{MS} values, and high selectivity in pH 4~6. These results were compared to slurries based H_2O_2 oxidizer.

11:30 AM E7.9
STUDY OF THE SEDIMENTATION PROCESS USING OPTICAL PATH-LENGTH SPECTROSCOPY. G. Popescu, W.G. Easter[a], A. Dogariu, School of Optics/CREOL, Univ. of Central Florida, Orlando, FL. [a]Lucent Technologies, Orlando, FL.

The slurry stability is determinant for the industrial processes involving CMP techniques. The sedimentation phenomenon that takes place especially in Cu CMP slurries depends on the structural properties at the mesoscopic level and may influence dramatically the result of the polishing process. Therefore, a noninvasive and accurate technique to investigate this phenomenon is desired. We have recently introduced optical path-length spectroscopy as a new technique for random media investigation. The principle of the method is to use a partially coherent source in a Michelson interferometer, where the fields from a reference mirror and the sample are combined to obtain an interference signal. When the system under investigation is a multiple-scattering medium, such as a CMP slurry, by tuning the optical length of the reference arm, the optical path-length probability density of light backscattered from the sample is obtained. This distribution carries information about the medium through the transport mean free path that characterizes the wave transport in the scattering medium. In addition, interference can be obtained between the reference arm and the top layer of particles in the suspension. During the sedimentation process, this layer will advance toward lower positions, creating a particle density gradient along the vertical direction. Using our interferometric technique, this gradient can be monitored in time, and the sedimentation process can be therefore quantified. In the present paper, we apply the optical path-length spectroscopy to investigate the sedimentation process in inhomogeneous distributions of particulate dielectrics. The experiments are performed on suspensions of different concentrations and particle sizes. We show that our method is highly sensitive to changes in volume concentration and particle size and that the spatial resolution achieved is better than 20 microns.

11:45 AM E7.10
SIMULTANEOUS REMOVAL OF PARTICLES AND DISSOLVED COPPER FROM COPPER-CMP WASTE STREAMS. Yuxia Sun, Srini Raghavan, Univ of Arizona, Dept of Materials Science and Engineering, Tucson, AZ; Brett Belongia, Millipore Corporation, Bedford, MA; James Baygents, Univ of Arizona, Dept of Chemical and Environmental Engineering, Tucson, AZ.

Chemical Mechanical Planarization {CMP} processes generate a large quantity of waste streams that contain abrasive particles, dissolved metal ions, and organic compounds. A typical waste stream for a copper CMP process may contain ~0.05 to 0.4% solids {alumina or silica}, ~5 to 40 ppm copper, certain complexing agents [ethylenediaminetetraacetic acid {EDTA}, or Ethylenediamine {EDA}], and corrosion inhibitors. A technique based on electrocoagulation has been investigated to remove particles and copper ions simultaneously from simulated and actual copper CMP wastes. In this technique, the waste sample is contained either in the anodic or cathodic chamber of an electrolytic cell using a membrane and exposed to an electric field. The key variables in the study were field strength, copper concentration, nature of complexing agent, the type of abrasive particles {silica or alumina}, and electrokinetic properties of membranes. It was found that over 85% of the abrasive alumina particles can be removed in 90 minutes from a waste stream containing 0.4% alumina {~200nm}. If the waste stream is held in the cathodic chamber, approximately 70% of copper can be plated out if EDA is present and a positively charged membrane is used. In the presentation, the removal mechanisms of both copper ions and particles under the application of electrical field will be discussed.

SESSION E8/D11: JOINT SESSION: PROCESS INTEGRATION AND MANUFACTURABILITY

Chair: Rajeev Bajaj
Thursday Afternoon, April 27, 2000
Golden Gate B2 (Marriott)

1:30 PM *E8.1/D11.1
CMP OF METALS. S. Kordic, H. Banvillet and R.M. Gonella, ST Microelectronics. *Philips Semiconductors, Crolles, FRANCE.

An overview is given of chemical mechanical polishing (CMP) of copper, aluminum and tungsten. Issues concerning the consumables selection, such as pads and slurries are discussed as well as their impact on process performance. Dual damascene integration and CMP issues of low-k dielectrics and Cu or Al metallization are discussed. Examples of electromigration performance of dual damascene Cu and Al are given.

2:00 PM E8.2/D11.2
TECHNIQUE OF SURFACE CONTROL WITH THE ELECTROLYZED DI WATER FOR POST CMP CLEANING. Mitsuhiko Shirakashi, Kenya Itoh, Ichiro Katakabe, Masayuki Kamezawa, Sachiko Kihara, Ebara Corporation, Precision Machinery Group, Kanagawa, JAPAN; Takayuki Saitoh, Kaoru Yamada, Ebara Reserch Ltd, Center for Technology Development, Kanagawa, JAPAN; Naoto Miyashita, Masako Kodera, Yoshitaka Matsui, Toshiba Corporation, Semiconductor Company, Kanagawa, JAPAN.

Recently, CMP is used for planalization for manufacturing of devices with multi-layer interconnects. Metal CMP processes have many subjects to look at because surface of wafer to be polished is composed of several materials - wiring material, interlayer dielectric, etc. In general, wafers after CMP process are contaminated with particles and metallic impurities. In post metal CMP cleaning process, it is important that wafers are cleaned without damages to each materials. In this paper, we report the basic characteristic of the electrolyzed DI water, and its effect on the wafer surface when used for cleaning after metal CMP by analyzing the wafer surface with XPS and other instruments.

2:15 PM E8.3/D11.3
STUDIES ON SELECTIVITY TOWARDS BARRIER LAYER IN COPPER CMP. Cue Wei, Dnyanesh Tamboli, Vimal Desai, Sudipta Seal; Advanced Materials Processing & Analysis Center (AMPAC), University of Central Florida, Orlando, FL.

Copper CMP is used to form interconnects in multi-level device fabrication with dual-damascene architecture. Copper is typically deposited on a oxide inter-level dielectric layer with a Ta/TaN barrier layer in between. One of the critical issues in copper CMP is to minimize dishing of metal lines during CMP. Dishing of copper lines is enhanced by low CMP removal rates for tantalum compared to copper, due to widely different mechanical and electrochemical behavior of copper and tantalum. Use of a slurry, which provides similar removal rates for both copper and the barrier layer, can minimize metal dishing in CMP. In this study we will examine the factors that affect the removal rates in copper and tantalum. In this study, CMP will be carried out with both copper and tantalum under identical conditions of polishing. Ex-situ and in-situ electrochemical measurements as well as X-ray Photoelectron Spectroscopy (XPS) are used to determine the removal mechanism in CMP of copper and tantalum. Based on these fundamental studies, slurries are designed to maximize the removal rates of both copper and tantalum.

3:00 PM *E8.4/D11.4
DEVELOPMENT OF A MANUFACTURABLE MULTI-LEVEL COPPER CMP PROCESS. Rajesh Tiwari, Greg Shinn, Vincent Korthuis, Somit Joshi, Texas Instruments, Dallas, TX; and Rajeev Bajaj, Fritz Redeker, Yutao Ma, Applied Materials, Inc. - CMP Division, Santa Clara, CA.

The dual damascene approach for forming copper interconnects has enabled the simultaneous formation of sub-0.25μm vias and trenches that are etched in dielectric prior to barrier, seed and bulk Copper deposition and subsequent CMP to remove the excess material. Additivity of topography with every subsequent metallization level, poses serious challenges on CMP process capability. Intermediate dielectric planarization is necessary to eliminate topography created during Cu CMP. This additional step adds cost and negates one of the potential advantages of dual damascene processing. There exists a need for Cu CMP process that meets the low topography requirements of multi-level damascene and meets device performance requirement for interconnect metal remaining. Process performance of high and low selectivity barrier removal slurries was evaluated for multi-level damascene applications. Initial topography was generated through the tungsten CMP process step. Experimental results show that underlying W CMP related topography has a detrimental impact on the polish performance at the first Cu layer CMP step. Overpolish requirements, to accommodate the underlying topography, for the high and low selectivity processes are different. Final topography achieved with both approaches are compared. Physical and in-line electrical data from the two selectivity processes will also be discussed.

3:30 PM E8.5/D11.5
REMOVAL RATE, UNIFORMITY AND DEFECTIVITY STUDIES OF CHEMICAL MECHANICAL POLISHING OF BPSG FILMS.
Benjamin A. Bonner, Boris Fishkin, Jeffrey David, Chad Garretson and Tom Osterheld, Applied Materials, CMP Division, Santa Clara, CA.

Borophosphorosilicate glass (BPSG) is currently a film of choice as pre-metal dielectric. The addition of phosphorous to silicate films may lower the migration of alkali ions, while boron addition lowers the glass transition temperature of the film allowing it to flow at lower temperatures to give better local planarity. The move toward sub-0.25 micron line width requires global planarity to achieve good depth of focus. This global planarization can be achieved by chemical mechanical polishing (CMP). The current study involved CMP of 200mm BPSG films. The dopant concentrations in the films ranged from 3.5 to 6.5 percent. Changing the concentration of boron and phosphorous had little effect on the uniformity of post-polished wafers, but had a strong effect on the CMP removal rate. In general the removal rate increased as the total concentration increased, with boron dopant concentration having a much stronger influence on the rate than phosphorous dopant concentration does. Information regarding the mechanism of the effects of dopant concentration on removal rate will be discussed. Defectivity was studied during the course of this project. Post-polish defect levels of BPSG films were lower than reference TEOS films, with few or no CMP microscratches. Analysis of the defects was performed using light scattering techniques and optical review.

3:45 PM E8.6/D11.6
POLISHING STUDIES ON MATERIALS RELATED TO SiO_2/Ti/TiN/W MULTILAYER STACKS.
V.S. Chathapuram, K.B. Sundaram, V.H. Desai, D.C. Tamboli, S. Seal.

Multilayer interconnections involving tungsten will consist of SiO_2/Ti/TiN/W layers. In the CMP process of tungsten, the polishing studies of these layers are very critical. In this study a detailed investigation is conducted on the polishing rates of these four layers by using bulk high purity targets. The parameter studied in this investigation is the polishing rate as a function of the applied pressure, table speed and slurry used.

4:00 PM E8.7/D11.7
USING WAFER-SCALE PATTERNS FOR CMP ANALYSIS.
Brian Lee, Terence Gan, Duane S. Boning, Dept of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA; Jeffrey David, Benjamin A. Bonner, Peter McKeever, Thomas H. Osterheld, Applied Materials, Santa Clara, CA.

Wafer-scale patterns [1] in CMP have previously shown promise as a tool to study CMP dependencies. A new set of wafer-scale patterns have been designed for detailed analysis and modeling of key CMP effects. The goal of this work is to explore the development of a methodology to characterize the planarization capability of a CMP process using these wafer-scale patterns; to determine a method of characterizing a pad deflection limitation that would affect the polish of particular patterns; and to explore the potential use of wafer-scale analysis to simulate the effects of nanotopography on CMP. There are two major avenues to approach for characterization of planarization performance. It is possible to determine the planarization length of the process via analysis of the trench removal for various feature sizes. Alternatively, planarization length may also be determined by analysis of the post-CMP transition region of the trench edge, after complete trench step height removal. Analysis of the deflection limitations of a particular pad can be performed by experimentation using different pads, step heights, and time splits. Post-CMP profilometry scans of the trenches will demonstrate the shape and deflection of the pad as it deforms into the trenches, and provide insight on flexing limitations of the pad. Nanotopography refers to the existing nanometer-scale surface variations that may be present on bare silicon wafers [2]. CMP of conformal films on such wafers can result in variation concerns in later stages of the process. Proper simulation of the effect of nanotopology on a post-CMP film can lead to analysis and diagnosis of potential problems. A methodology of using wafer-scale patterns for CMP analysis will be described. Implementation of wafer-scale patterns via traditional, as well as alternative means, will also be discussed. [1] Peter Burke, MRS 1996 [2] K.V. Ravi, Future Fab International, Issue 7, pp. 207.

4:15 PM E8.8/D11.8
NEW TECHNIQUES FOR IN-SITU CMP END-POINT METROLOGY.
Mehrdad Nikoonahad, Shing Lee, Guoheng Zhao, Kalman Kele and Kurt Lehman, Film and Surface Technology Division, KLA-Tencor Corporation, San Jose, CA.

A new technique for in-situ end point metrology in chemical mechanical polishing (CMP) is reported. This technique is based on a recently developed self-clearing objective (SCO) in conjunction with multi-angle reflectometry at a single laser wavelength. The SCO sets up a small local jet of DI water in the vicinity of the wafer during CMP and it offers a number of advantages. Firstly the slurry and any debris in the optical path are essentially removed and hence we make the in-situ measurement through DI water. Furthermore, the SCO alleviates the need for a soft window and all problems associated with it. These advantages enable us to preserve angular resolution and hence perform multi-angle reflectometry during CMP. The wafer is illuminated at 9 separate angles simultaneously and, using the multi-angle data, we solve for the film thickness, which is report dynamically during CMP. It is, therefore, clear that end-point detection is a subset of the overall end point metrology. Without the SCO the diffuse scattering in a potential soft window material together with scattering resulted from surface scratches lead to a significant cross-talk and hence loss of angular resolution between adjacent channels. The basic design of the SCO is discussed and considerations for avoiding slurry dilution are presented. It is shown that this technology has zero impact on the CMP process. Typical results from copper and oxide (ILD and STI) CMP are presented and excellent agreement between the measurement and theoretical prediction is demonstrated. We stress that agreement between theory and experiment is essential so that data may be inverted to compute film thickness during polish. This strategy is fundamentally different from empirical end point detection this is the present-day approach in techniques that use a single beam at single wavelength through a soft window. Finally advantages of multi-angle over multi-wavelength for data inversion are presented.

4:30 PM E8.9/D11.9
PLANARIZATION OF COPPER DAMASCENE INTERCONNECTS BY SPIN-ETCH PROCESS: A CHEMICAL APPROACH.
Shyama P. Mukherjee and Joseph A. Levert, Allied Signal Electronic Materials, Sunnyvale, CA; Donald S. DeBear, SEZ America Inc, Phoenix, AZ.

During the metallization of dual damascene structures, excess copper is electrodeposited on field areas in order to achieve a complete filling of vias and trenches. The removal of excess copper and planarization of the surface is typically achieved by chemical-mechanical polishing (CMP), where mechanical force in the form of downward pad pressures and chemical effects in the form of a dispersion of ceramic particles are utilized. In this work, we present a chemical planarization approach, Spin-Etch Planarization (SEP) to accomplish the dual tasks of planarization and excess material removal. The present approach is based on the controlled wet chemical etching and polishing of the copper layer. The chemical etching solution, having no ceramic particles is dispensed onto the wafer's surface while it is spinning. The physico-chemical nature of the etchant and processing conditions such as the spin-speed of the wafer and dispense pattern of the etchant are selected to simultaneously achieve uniform removal of copper and planarization of local recesses of the different feature sizes in the plated copper surface over the entire 200mm wafer. This process is based on controlled wet-chemical etching, which involves a higher metal dissolution-rate at surface projections, and on peak areas and a lower metal dissolution-rate at crevices or in recesses. This technique leads to a leveling of the as-deposited surface features. Once planarization of the surface topography by the uniform and selective removal of copper is achieved, a different etchant is used for the selective removal of the barrier layer(s). At this step, the exposed planarized copper features are kept passivated while the removal of barrier layer is achieved. In this work, we will present the basic concepts and process principles of SEP and the results of planarization obtained with 200 mm electroplated patterned copper wafers. We will also describe the key features of the SEZ Spin-Etch system that contributes to process performance and manufacturability.