SYMPOSIUM E

Fundamentals and Materials Issues in Chemical-Mechanical Polishing of Materials

April 26 – 27, 2000

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Proceedings published as Volume 613
of the Materials Research Society
Symposium Proceedings Series.

*Invited paper
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 pressure, 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. Raj K. Singh, Uday Mahajan, Seung-Mahn Lee, Anupam Nagy and Zhou 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 potentialistic) 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 electrodynamic effects in W and Cu. Based on electrochemical measurements and tribological measurements, correlations between the CMP removal rate and chemical reaction rates will be determined. The mechanism for CMP removal rates will also be discussed.

10:30 AM E1.6
MODELLING ON MECHANICAL PROPERTIES OF POLISHING PADS IN CMP PROCESS. Takashi Nishikawa, Susumu Iwami, Takashi Kawakami, Toshio Co, Corporate Research & Development Center, Kawasaki, Japan; Yoshiaki Theeyam, Hiroshi Ohtani, Naoto Miyahara, Toshio 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 density and mechanical properties of polishing pads. In order to simulate the topology 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 superimposed 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 silicon slurry and stacked pad of polyurethane and non-woven fabric. The compressive elastic modulus 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 of the slurry on the polishing rate and the removal rate. The effect of the concentration of the abrasive particles on the CMP rate is also studied.
and solids loading in SiO₂ CMP. In this study, polishing experiments were conducted with SiO₂ slurries to which different concentrations of metal halides (NaCl and NaBr) and surfactants 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 (SiO₂, Al₂O₃, CeO₂, ZrO₂, TiO₂) with similar particle sizes were used to conduct polishing experiments. Thinner layers were created for four different pHs. The results showed a clear dependence of polish rate on the nature of the abrasive, with CeO₂ showing the highest polish rate. In addition, significant particle deposition was observed on the SiO₂ wafer surface at the point of minimum stability of the different abrasives.

1100 AM E2.8 DOUBLE-KINK THEORY APPROACH IN CMP MODELING
Valeriy Sakhariev, LSI Logic Corporation, Santa Clar, 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 streaming. The primary focus is to explain the dependence of the polishing rate on the pattern density and to express polishing rate quantitatively 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 described in this model is the formation of a critical size pit (nucleus) 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 induced by the stress-enhanced dissolution of any step edge atom and followed by the fast dissolution of the newly formed corner atom. This mechanism can be described as formation of a double kink site at the step edge, followed by motion of the single kink. The time required for dissolution of the entire surface layer is determined by the time for critical pit nucleation and for the annihilation of the neighboring pits. Assuming applicability of the Zhrkov-Kharchenkov expression for the roughness-enhanced rate of impinging etching, we can express experimentally confirmed subsurface pressure dependence in Preston's 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 mechanisms can be expected. This new physically based model can describe the metal dusting and oxide erosion rates in a variety of pitch structures and predict the dependence of the IL polishing time as a function of pre-CMP profile and major process parameters, such as chemical and mechanical polish characteristics, applied pressure, relative pad/work 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-Tso Tseng, James Niu, Rick Lu, Dept of Materials Science & Engineering, Taihwa, Taiwan.

The introduction of damascene and dual-damascene processes for ULSI multilevel interconnects beyond 0.25um generation has prompted the development of chemical-mechanical polishing (CMP) for Cu thin films. In Cu films, copper forms a native 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 native oxide layer may be critical to CMP, the removal of this layer is also heavily affected by the chemical characteristics (e.g., pH and oxidation potential) of the slurry used, the removal of which may be dual chemical and mechanical nature. Results of our preliminary study show that the frictional force during Cu CMP is sensitive to the pH, and can be not negligible in Cu-flushed peroxide slurries. 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 forces between particles and surface. To further study 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 used high sensitivity 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 ablation. Frictional behavior, electrochemical measurements, and surface characteristics of TiN with and without Cu CMP will also be investigated. The behaviors exhibited by Cu and Ta/Ni will be compared so as to help unravel the mechanism during Cu CMP for damascene-based Cu interconnects.

2:00 PM E2.3 ANALYSES OF COPPER DAMASCENE STRUCTURES AND CHEMICAL-MECHANICAL POLISHING. Tae-Soon Park, Subha 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 disease performance. Due to difficulty in the etching of copper, the chemical-mechanical polishing (CMP) process is introduced. This presentation will describe four analytical and computational analyses of the Damascene process for unpassivated and passivated copper interconnect lines with the objective of understanding the differences and stresses along and across the lines for various process conditions, thermal loading, and a wide variety of practically relevant trench, line, and interconnect geometries. The analysis of the CMP process is compared with experimental observations. The geometrical effects of thermomechanical deformation as a consequence of chemical- mechanical polishing are also examined systematically.
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 silicon are widely used as abrasives for Cu and Ta CMP. While alumina is harder than silicon and hence gives higher polish rates, cost concerns favor the use of silicon abrasives. This paper will discuss copper and tantalum polishing results using alumina and silicon abrasives in the absence and presence of various slurries chemistries. The use of alumina and silicon 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 silicon 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, hydrazine, aluminum permanganate, etc., using both silicon 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 wear 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 silicon 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.

E3.3 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 Harind, Steve Langford, Tom Dickinson, Washington State University, Dept. of Physics, Pullman, WA.

When you have a dent in the wall one does not wear many 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 experiment involves 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.

E4.1 A NOVEL SINGLE STEP LAPPING AND CHEM-MECHANICAL POLISHING SCHEME FOR ELEMENTAL AND COMPOUND SEMICONDUCTOR MATERIALS USING 1 μm ALUMINA SLURRY: P.S. Dutta, B.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 I. 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 included: GaSb, InGaSb, InGaAs, InAs, GaAs, InGaAsSb, CdTe, CsZrTe, Si, and Ge. Surface damage resulting from wafer splitting could be eliminated 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 0.5 micron abrasive. The effect of different pad materials 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 velcros 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 0.63 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 super-flat 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, Minid Weling, Philips Semiconductors, San Jose, CA; Michele Cecchi, Francine Rios, Strathclyde, San Luis Olalco, 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 mechanism 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.

**E4.4**
**MULTILEVEL DAMASCENE PROCESS DEVELOPMENT:**
**ALUMINUM CMP**

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 layer. 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 multi-level aluminum damascene process, aluminum CMP would remove the entire aluminum over-layer with no dying 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 height with no defects. Physically however the barrier material has a removal rate that differs from the aluminum material. This causes dying of the bond pads and electrical lines. The extent to which this occurs is proportional to the local device dimensions and polishing pad non-uniformity. Hence the key CMP metrics to control the dying and oxide erosion are the non-uniformity and the step time or end pointing of the CMP process. However link to both the dying and oxide erosion are the scratches imprinted due to the CMP planarization step. This due to the fact that large scratches require increasing 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.

**E5.1**
**IMPROVEMENT OF Wafer EDGE PROFILE AND CMP PROCESS PERFORMANCE THROUGH THE FLOATING HEAD DESIGN:**
Huey-Ming Wang, Gerry Moloney, Mario Stell, Senindo DeGuzman, Cybeg 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 and beyond. Due to the tighter CMP process spec, it is very important to reduce the within wafer non-uniformity (W/NWU) at small edge exclusion to allow higher process yield. The improvement of the CMP process performance might go through the modification of either the polishing pad, the consumable sets, or both. The better solution is through the change of head design for a fixed plate from the polishing pad 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 clean up the edge profile by breaking the matched speed rule. The best W/NWU% 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 retainer-ring pressure chamber is separated from the sub-carrier. The average W/NWU% is about 4% for 3-mm and 5-mm EE from two-pressure-chamber head. Due to the limitation of retainer-ring pressure effect, a third pressure chamber is further added to control the wafer edge profile that is extended to 1 inch from the wafer edge. The W/NWU% is about 3.8% at 8-mm edge exclusion with low down forces. The sharp and insert types also show effects on the wafer edge profile, and it is shown that this three-pressure-chamber head is able to reduce the post-CMP thickness variation from the ILD polishing 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 TUNGSTEN DURING CHEMICAL-MECHANICAL POLISHING:**
PingLin Kuo, Dept. of Chemical Eng., Wei-Tsu Tseng, Rick Lu, Dept of Materials Sci. & Eng., Chun-Lung Liao, Dept of Chemical Eng., 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 pattern density of some localized features of silicon nitride exacerbate the problem. Results from our preliminary work indicated that the addition of only finite amount of surfactant and wetting agents into the conventional silicabased alkaline slurries brought about no significant changes 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 performed as a potential factor influencing the polish selectivity. In the present work, silicon-based and organic-based surfactants and wetting agents will be added to conventional silicabased oxide slurry for the fine-tuning of oxide and nitride polish rates. A test vehicle wafer 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.** Naoito Miyashita, Meiji Univ., Dept of Electrical and Electronic Engineering, Toshiba Co., Semiconductor Company, Yokohama, JAPAN; Shin-Ichi Uekusa, Meiji Univ., Dept of Electrical and Electronic Engineering, Kawasaki, JAPAN; Takeshi Nishio, Hitachi, Kawasaki, JAPAN.

Chemical-Mechanical Polishing has been revealed as an attractive technique for poly-Si of trench planarization. Major issue of the process integration is pattern erosion after over polishing. A new process with silicon slurry containing organic surfactant is reported in this paper. A pattern 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 an 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 recovering poly-Si by CMP, because it keeps the erosion level very low.


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 the electrolyzed water as an alternative method 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 active water of the acidity/high ORP and the cathode water of the alkalinity/low ORP by electrolyzing ultrapure water adding with a small quantity of chemicals; 2) this system can generate active water and cathode water at the same time or separately; 3) if necessary, the active water can be diluted with DI water at the optional quantity, and it is possible with the cathode water that hydrogen peroxide is added. The active 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. A feature of this paper was the outline of ultrapure water electrolyzed water supply system and the basic characteristic of the water made with this system.

**E5.5 POST CMP CLEANING: CHALLENGES BEYOND BLANKET**

**WAFTER DEFECTS.** Brian Frider 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 6410). 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 microroughness, 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 blanket defect marks) will also be discussed. Defects will be discussed for both CMP and CMP free 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 megasonic) 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 Osterfield, 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 technologies must be constantly improved, replaced or invented. Chemical mechanical polishing (CMP) is the latest processing technique to be incorporated in the manufacture of metal interconnect circuits as the industry adopts sub 0.25 micron technology. CMP is currently the production method of choice to planarize pre-metallic 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 has significant cost or performance implications. For these reasons a direct 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 slurries. 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.** Sun Tsai, Robert Mundel, 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 for the first time. The results are especially related to chemical mechanical polishing issues in copper slurries, including the mechanical strength of the material, the choice of the cap material and the use of sacrificial 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 were 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. Li, 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 polishing (CMP) processes for low-k materials. This work examines 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 hydrophilic surface. On the other hand, it is clear that slurries containing silica surface treated fluorinated polyimide from hydrophilic to hydrophobic to enhance the removal rate of fluorinated polyimide.

SESSION E6: POSTER SESSION:
CMP CONSUMABLES
Wednesday Evening, April 26, 2000
8:00 PM
Salon 1-7 (Merrill)
commercial slurries, Nalco-371 which is commonly used for stock removal polishing in wafer industry. Prepared slurries showed comparable performance to commercial slurries 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. Ramadoss, V. Deshi, Advanced Materials Processing & Analysis Center (AMPAC) and Mechanical, Materials and Aerospace Engineering (MMAE), University of Central Florida, Orlando, FL.

The current USL1 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 interconnects which are of the line widths 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 H2O2 and KIO3 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-cell) 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 forces 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 behaviour and performance depend on the microstructure of the pads. This presentation will illustrate our findings 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. Rindon Enswink, Seungkwon Hong, Vinimkar Deshi, AMPAC, University of Central Florida, Orlando, FL; John M. Rice, Charles Storey, William Easter, Lucent Technologies, Orlando, FL.

Characterization and stability of two common CMP slurries were evaluated focusing on their behavior 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 potential (electrochemical 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 polycarbonate depth filters. These filters are designed for the CMP industry to remove particles that are in the size range of 0.25 - 250 microns and for general applications. The results of the filtration tests were analyzed and presented.

E6.9 CHARACTERIZATION OF POLISHING PADS BY A LOW-COHERENCE OPTICAL TECHNIQUE. Lorence Denney, Claudia Mujir, Arisdi Doganis, School of Optics/CREOL, Univ. of Central Florida, Orlando, FL.

Chemical mechanical polishing (CMP) is a tribocorrosion process used in the planarization of silicon wafers by the concurrent interaction of a polishing pad, a wafer, and a semiconductor wafer. The removal of 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 a technique of optical pathlength spectroscopy (OPS) that we have recently introduced. Through this noninvasive technique, changes in optical properties are measured in situ 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 structural 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 Mujir, Lorrence Denney, Aristode Doganis, 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 contact, nondestructive optical technique to measure the 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, we investigate the optical 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 analytical and/or numerical models, and the porosity of the sample can be determined. In the case of filters with thickness 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 cannot be represented analytically. As a direct result of the measurement, the thickness of the filter is determined independent of porosity.

SESSION E7: CMP CONSUMABLES
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 Titus, Mechanical and Aerospace Engineering Department, Rensselaer Polytechnic Institute, Troy, NY.

Interfacial pressures have been measured at a pad/fixture interface sliding over a polishing plane. The fixture is not rotated during sliding. The speeds of sliding and loads on the fixture are in the range of 0.25m/s and 1500N respectively. The fixture geometry is flexible so that a dome shape (amplitude of approximately 100 microns) can be imposed on the 10mm 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, Balhe Brant, Yakov I. Rubanovitch, Beir M. Mozaffari, 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 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 these features include x-ray diffractometry, and surface profilometry. If the apparatus (SFA) and atomic force microscopy (AFM) can apply pressures equivalent to those during CMP, but because of the large amount of surface area and the difference in the forces between different conditions, accurate results are difficult to reproduce. To facilitate some of the mechanisms of polishing, a micro-structural investigations of experiments in several different environments (alkali, abrasive) and CMP substrates (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 different pads 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.
Jian Li, Kersten M. Forsthoefel, Kathleen A. Richardson, School of Optics/CREOL, Department of Chemistry, University of Central Florida, Orlando, FL, Yaw S. Oheng, William G. Enzer, 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 aspects and present a method of performing tests performed on pads, slurries and their interaction. Specifically, this paper will address the interaction between the polyurethane-based pads (IC1010, Suba IV, IC1008/Suba IV) and some commercial slurries (M2000, K解锁 1486, K解锁 1501). The corresponding variation in pads hardness, absorption, morphology, microstructure and mechanical integrity in various pH (slurry chemistry) and organic (DMF, DMDSO) 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 nucleophile species (e.g., OH-) can attack the carbonyl center (CO) of the urethane structure, effectively destroying 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 NH₄OH SLURRY FOR COPPER CMP.
Vee S.C. Lee, David W. McNell, Harold S. Gamble, Queen’s University of Belfast, Dept. of Electrical and Electronic Engineering, Belfast, NORTHERN IRELAND.

Chemical mechanical polishing (CMP) of copper (Cu) metallization using Benzo triazole (BTA) containing NH₄OH slurry has been treated in this work. Two efficient Chemical mechanical polishing (CMP) and continual mechanical abrasions due to the deformed pad bonding into the Cu recess region results in a serious dishing phenomenon, i.e., thinning of the Cu lines. The formation of a thin Cu(BT)-Cu polymer over the recessed Cu proves to be an effective method of protecting the Cu from chemical dissolution and minimizes mechanical abrasion, and hence dishing is significantly reduced by a factor of 9. Cu polish rates in BTA containing slurry are generally lower than that without BTA. It was found that the polishing rate decreases with increasing BTA concentrations in the slurry, but saturates when BTA concentration exceeds 0.25 wt. %.

AFM studies showed that the grain size-deposited Cu surface was roughened after subsequent CMP processes. Electromigration resistance test structures have been successfully patterned using 2-step CMP etching scheme.

10:15 AM E7.5
MEASUREMENTS OF SLURRY FILM THICKNESS AND MIXING DURING CHEMICAL MECHANICAL PLANARIZATION.
Aria Philippou1, Jonathan Coppett1, Jonathan Lu1, Mansour Monpour2, Chris Rogers3, Liviu Racz2 and Frank Kaufman1, Intel Corporation, 6000 McCarthy Blvd, Milpitas, CA. 1Tufts University, Department of Mechanical Engineering, Medford, MA. 2Cabot 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 technique can be used to measure temperature and pH gradients during the polishing. A model of uncoiled fluorescence, a design of experiment was conducted to show the interdependencies of polishing parameters such as photon speed, flow rate, down force, conditioning, pad type, and pad manufacturer and how this affects slurry transport and slurry mixing. With a Deltek 208i profilometer we are able to study the effects of pad topography on polishing uniformity. So far our experiences indicate polishing rates of 1000 to 2000 Auminum per minute depending on the type of substrate. 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. Sen, 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 brain consumables such as abrasives, pads, slurries, etc. The process is very dynamic and thus a thorough understanding of the laminar nature of removal results at the CMP surface. Various CMP consumables interaction is required. CMP pads are primarily polyurethane based materials. This paper reports the application of X-ray photoelectron spectroscopy to map the pad surface chemistry. The analysis of the elemental composition from the various CMP consumable interaction was performed. The results suggest that the pad surface is primarily organic in nature.

This technique allows us to nondestructively evaluate the pad material providing both elemental and chemical state information. Furthermore, AFM is used to track the topographic variation of pads and correlates to removal rates, within wafer nonuniformity and other pad parameters. (The work is supported by Lucent Technologies.)

11:00 AM E7.7
IN-SITU FRICTION FORCE MEASUREMENTS IN CMP.
Udy Majhajn, Seang-Mahn Lee and Rajiv K. Singh, Department of Materials Science 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 additional 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 the change in friction force due to changes in pad conditions, as well as 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 processes and develop a 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. Seang-Mahn Lee, Udy Majhajn, Anupam Nagroy, Zhou Chen, Valerie Gucun, and Rajiv K. Singh, Department of Materials Science 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 ensure high removal rate, good planarity, and relatively high selectivity over SiO₂ using intermediate pH slurries. They are based on forming a protective passive layer on the copper surface with Benzonitrile (BTA) and potassium iodide (KI) and enhancing the dissolution rate of copper in the slurries by using a complexing agent, ethylenediamine tetraacetic acid (EDTA), in slurries containing potassium iodate (KIO₂) oxidizer. The characteristics of these slurries were investigated using a variety of characterizations including acid base titrations, 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 CuI compound passive layers on the copper surface. Additional EDTA enhanced the polishing rate due to increased dissolution rate of anodized copper particles. Therefore, slurries with BTA and EDTA or with KI and EDTA are shown optimal results, i.e., relatively high removal rate, low H$_2$O$_2$ values, and high selectivity in pH 4–6. These results were compared to slurries based H$_2$O$_2$ oxidizer.

11:30 AM E7.9

The slurry stability is determined for the industrial processes involving CMP techniques. The sedimentation process that takes place in Cu CMP slurries depends on the structure and physical properties at the mesoscopic level and may influence dramatically the result of the polishing process. Therefore, a non-invasive and accurate technique to investigate this phenomenon is desired. We have recently introduced optical path-length spectroscopy as a new technique for random media investigations. 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 multi-scattering medium, such as a Cu CMP slurry, by tuning the optical length of the reference arm, the optical path-length probability density of light back-scattered from the sample is obtained. This distribution contains 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 0.2 microns.

11:45 AM E7.10
SIMULTANEOUS REMOVAL OF PARTICLES AND DISSOLVED COPPER FROM COPPER-CMP WASTE STREAMS. Yuxin Sun, Srin Raghware, Univ. of Arizona, Dept of Materials Science and Engineering, Tucson, AZ; Brett Belongia, Milligore Corporation, Bedford, MA; James Bygents, 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, dissolced metal ions, and organics. A typical waste stream for a copper CMP process may contain 0.5 to 0.15% solids (alumina or silicon). ~0.02 ppm copper, certain complexing agents [ethylene diamine tetraacetic acid (EDTA), or Ethylendiamine (EDA)], and corrosion inhibitors. A technique based on electroconjugation has been investigated to remove particles and copper ions simultaneously from simulated and actual copper CMP waste streams. In this technique, the waste sample is contacted either in the modic and/or cathodic chamber of an electrochemical 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 (silicon or alumina), and electrokinetic properties of membranes. It was found that over 95% of the abrasive alumina particles were removed from a waste stream containing 0.4% alumina (0.20mM). 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 present study, the removal mechanism 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 *E8.5/D11.1

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 clock dielectric 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. Mitsuhiro Shirakami, Kenya Ishi, Ichiro Katakabe, Masayuki Kawayama, Satoshi Kikuta, Elbara Corporation, Precision Machinery Group, Komagawa, JAPAN; Takayuki Sato, KINSERT Two, Elbara Research Ltd, Center for Technology Development, Komagawa, JAPAN; Moto Miyaishi, Masako Koidera, Yoshitaka Muraui, Toshiba Corporation, Semiconductor Company, Komagawa, JAPAN.

Recently, CMP is used for planarization 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 damage to each materials. In this paper, we report the basic characteristics 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. Yue Wei, Dong-Sheng Tan, Vimal Das, Shang-Wei 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 dielectric thickness during CMP. Dishing of copper lines is enhanced by high 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. Etching and in-situ electrical 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 minimize the removal rates of both copper and tantalum.

3:00 PM *E8.4/D11.4
DEVELOPMENT OF A MANUFACTURABLE MULTIPLE-LAYER COPPER CMP PROCESS. Rajesh Trivedi, Greg Shim, Vincent Korthuis, Scimitar Tech, Texas Instruments, Dallas, TX; and Rajeev Bajaj, Fritz Redeker, Yutuo Ma, Applied Materials, Inc. - CMP Division, Santa Clara, CA.

The dual damascene approach for forming copper interconnects has enabled the simultaneous formation of sub-0.35µm vias and trenches that are etched in dielectric prior to barrier, seed and build Copper deposition and subsequent CMP to remove the excess material. Activity of topography with every subsequent metal layer, 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 requirement of multi-level damascene and meets device performance requirement for interconnect metal remaining. Process performance of high and low selectivity barriers is essential 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 analysis with both approaches is performed. 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 Garrenin, and Tom Osterfield, Applied Materials, CMP Division, Santa Clara, CA.

Borophosphosilicate glass (BPSG) is currently a film of choice as a pre-metal dielectric. The addition of phosphorous to silicon 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 trend towards 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 dopant 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.

3:45 PM E8.6/D11.6
POLISHING STUDIES ON MATERIALS RELATED TO SiO2/T/TFN MULTILAYER STACKS.
V.S. Chalasparum, K.B. Sundaram, V.H. Desai, D.C. Tamboli, S. Sen.

Multilayer interconnections involving tungsten will consist of SiO2/T/TFN 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.

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 develop the exploration of a methodology to characterize the planarization capability of a CMP process using 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 means to approach 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 planarization 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 trench, 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 in traditional, as well as alternative means, will also be discussed. [1] Peter Burke, MRS 1996 [2] K.V. Rau, Future Fab International, Issue 7, pp. 207.

4:15 PM E8.8/D11.8
NEW TECHNIQUES FOR IN-SITU CMP END POINT METROLOGY.
Mehrdad Niloosheh, Shing Lee, Guoheng Zhao, Kalamane Kele, T. M. Kim, 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 selective 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 working slurry dilution are presented. It is shown that this technology has zero impact on the CMP process. Typical results from copper and oxide (HFCVD) 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 polishing. This stress is significant since 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 DAMASCENI INTERCONNECTS BY SPIN-ETCH PROCESS: A CHEMICAL APPROACH.
Shyama P. Mulkerjee and Joseph A. Levert, Allied Signal Electronic Materials, Sunnyvale, CA; Donald S. DeBent, SEZ America Inc., Phoenix, AZ.

During the metallization of dual damascene structures, excess copper is electroplated on field areas in order to achieve a complete filling of via 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 copper 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. By tailoring the physical-chemical parameters of etchant and processing conditions such as the spin-speed of the wafer and dispense pattern of the etchant, selectivity is achieved via simultaneous 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 electroplated 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.