Plasma Science and Technology
Room 213A - Session PS+MS-TuA

45nm Node with Panel Discussion

Moderators: B. Ji, Air Products and Chemicals, Inc., G. Oehrlein, University of Maryland

1:20pm **PS+MS-TuA1 Preliminary Investigations for Ultimate Gate Patterning***, E. Pargon,* LTM-CNRS, France*; **J. Foucher,*** CEA-LETI, France*; J. Thiault, O. Joubert,* LTM-CNRS, France

The fabrication of a sub-20nm transistor gate requires a very accurate control and understanding of all the plasma steps (resist trimming, BARC, hard mask open and gate etch) involved in the gate stack processes. Then, it is important to study the parameters that can generate a deviation of the final gate dimension for each of these plasma steps. The two aspects that we have studied are the etching behaviour of the photoresist mask exposed to the plasma, and the chemical nature of the layers that deposit on the reactor walls and feature sidewalls during the process. We have developed an experimental procedure using XPS analyses to characterize the chemical modifications occurring on the tops and sidewalls of the photoresist mask as well as the chemical nature of the coatings formed on the chamber walls. These analyses can be correlated with the process performances (in terms of etch profile and critical dimension control (CD control). SEM observations and CD AFM 3D have been used to get the process performance. In all the plasma conditions investigated, the BARC and hard mask opening steps both lead to a CD deviation of 5 to 15 nm attributed to the modifications of the photoresist mask during plasma exposure. XPS analyses and 3D AFM measurements show that the passivation layers formed on the pattern sidewalls during the gate etch step itself are strongly influenced by the pattern density and etch chemistry. Finally, we show that the only way to control gate etch processes in the sub 20 nm range is to minimize strongly the formation of the passivation layers on the gate sidewalls.

1:40pm **PS+MS-TuA2 EUV Light Source Development and Debris Mitigation For 45nm Node Lithography and Beyond***, **B.E. Jurczyk,** M.A. Jaworski, M.J. Neumann, M.J. Williams, D.N. Ruzic,* University of Illinois at Urbana-Champaign

Discharge-produced plasma (DPP) light sources are leading candidates for generating 13.5-nm wavelengths needed for next-generation optical lithography. Traditional DPP sources have used xenon radiators due to its cleanliness; however, high output requirements (>115W at first focus) are driving developers towards higher conversion efficiency fuels such as tin. As a result, condensable tin vapor and electrode debris reaching and damaging the first collector optic is a serious concern for device lifetime and cost of ownership. A secondary-plasma debris mitigation technique was successfully demonstrated for noble gas light sources at the Illinois Debris-mitigation EUV Applications Laboratory (IDEAL). The IDEAL facility utilizes a dense plasma focus discharge source operating at nominal conditions of 15 J/pulse, 50 Hz rep rate, and 3 kV. Electrode sputtered debris is re-ionized in a secondary plasma region and removed with a biased foil trap prior to the collection optics. For a low density plasma (10@super 9@ cm@super -3@) condition, a debris removal fraction of 61% ± 3% was observed. The experimental chamber has been modified to operate with tin delivery into the pinch region. Results from electrode redesign, tin injection, EUV light output and condensable tin vapor mitigation will be presented. High density results from an improved internal helical-resonator shielded inductive coil configuration give greater protection efficiency. Fast ions contributing to optic erosion have been observed. Results from a gridded energy analyzer shows two peaked ion distributions at 2.8 keV and 5.8 keV. Elevated plasma potential and sheathing effects have shown an increase in ion energy at the boundaries. An improved ESA/TOF system provides < 5 eV spectral energy resolution and information on charge/mass ratio. Preliminary results from the new Surface Cleaning of Optics by Plasma Exposure (SCOPE) facility are presented for advanced fuel interactions on optical components.

2:00pm **PS+MS-TuA3 Fundamental Studies on Low-k Processing***, **T. Tatsumi,*** Sony Corporation, Japan **INVITED**

The need for reliable low-k/Cu interconnect technologies is increasing, and many kinds of low-k materials have been proposed. We need a process design for etching that will correspond to a change in the film densities and compositions of low-k materials for 90 and 65-nm node devices. Using many different in-situ plasma-measuring tools, such as IRLAS, OES, surface wave probes, and QMS, we counted the absolute number of incident species (CF@sub x@, O, N, H, F, radicals and ions) that were dissociated and/or ionized in fluorocarbon plasmas. Next, we evaluated the surfaces of the various SiOCH films (k = 2.9-2.2) that had different film compositions and densities, and that had been exposed to various fluorocarbon plasmas. The etch rates, selectivity, and thicknesses of the surface polymers were analyzed. We found that the etch rates of the SiOCH films depended on both the "total number of F atoms in all of the incident CF@sub x@ reactive species", and "the surface reaction probability, which depends on ion energy". Lower oxygen concentrations in SiOCH film induce a narrower process window because the fluorocarbon polymer became thicker, even during lower incident CF@sub x@ flux conditions.@footnote 1@ As a result, the etch rate became very sensitive to changes in the incident CF@sub x@ fluxes, resulting a narrow process window for etching SiOCH and porous SiOCH materials. To ensure reliable interconnects for 45 nm and beyond, we require new technologies to realize both "quantitative control" and "instant stabilization" of the plasma parameters. Furthermore, we also need to develop a model to control the atomic layer modification (etching and/or degradation) of the actual etched surface for various materials. Cooperation between etching and other unit process engineers must be promoted in order to create a more reliable process module. @FootnoteText@ @footnote 1@ T.Tatsumi et al, Proceedings of the 2003 IITC (2003) 239.

2:40pm **PS+MS-TuA5 Plasma Etch Challenges for 45 nm Node and Beyond***, **R. Wise,*** IBM **INVITED**

Many novel technologies are candidates for introduction at the 45 nm technology node. Metal gate electrodes, high-k gate dielectric materials, hybrid oriented transistors (HOT), FINFET transistors, new silicide materials, multiple stressed liners, fully-silicided gates, and porous low-k BEOL materials are all currently under evaluation for introduction at the 45 nm node. The anticipated impact of each of these technology components on requirements of dry etch process and tooling is discussed in detail. Lithographic limitations will continue to require dry etch processes (e.g. gate, contact) to provide additional CD reduction to meet designed groundrules. These processes will include extension of well-known resist trim techniques as well as other techniques, such as providing a controllable taper through a sacrificial masking material. Available resist material will be reduced both by limitations of the lithographic process window (N.A , DOF, resolution) as well as implementation of multiple exposure techniques. These reductions in the available mask thickness required to preserve lithography process window have driven the need for highly selective etch processes, generally at the expense of uniformity (especially on 300 mm wafer sizes), defectivity, and profile of the transferred pattern. Later generation lithographic materials are expected to continue to exhibit increased sensitivity to line edge roughness. Process and tooling needs required to address these lithographic challenges are discussed.

3:20pm **PS+MS-TuA7 Invited Panel - "Challenges for 45 nm Node"***, C. Gabriel,* AMD (damage)*; M. Hussein,* Intel (scaling)*; C.-J. Kang,* Samsung (dielectric etch)*; S. Wege,* Infineon (silicon etch)

Panelists will present 5-minute perspectives.

3:40pm **PS+MS-TuA8 Discussion - "Challenges for 45 nm Node" Panelists and Attendees***,*

Manufacturing Science and Technology
Room Exhibit Hall B - Session MS-TuP

Poster Session

**MS-TuP1 Reactive Preclean H@sub 2@/He Plasma Prior Copper Deposition, Investigation on the First Wafer Effect and Multivariable Advanced Process Control*, R. Petri*, *L. Bucelle,* STMicroelectronics, France

As a general concern in the semiconductor industry, the process stability is crucial and the methodology to ensure this stability becomes more and more complex. By years, the submicron technology constrains the manufacturing to introduce thorough process controls: initially guaranteed by specification limits only, it was improved by the introduction of control limits and Statistical Process Control. Recently, the industry is moving to Advanced Process Control based on a multivariable control of machine parameters. By this way, those parameters can eventually be correlated with product yield. On another hand, process integration becomes extremely sensitive to the process environment and therefore any uncontrolled modification of the reactor surface, such as reactor wall state, wall temperature, in-situ plasma clean, could generate a process drift and may induce severe yield lost or reliability issues. As a consequence, the study and the eradication of the first wafer effect, due to its impact on the manufacturing performances, has generated a lot of focus and publications. This paper is an application of the Advanced Control Process to ensure the stability of the reactive H@sub 2@/He plasma preclean process used in dual damascene structure prior copper deposition. It shows that tiny variations of the wafer processing context are easily detected by appropriate APC model. It appears that plasma potential is very dependant on process controlled parameters but also varies significantly with substrat nature as well as reactor wall temperature. We show that any process drift from the standard expected behavior is detected with the developed model. The nature of the deviation (i.e. signature) is also given. Therefore, in a manufacturing environment, APC is an extremely versatile methodology which can detect in line process drift, but also allows more fundamental investigations, like first wafer effect understanding and eradication, much easier, faster and cost effective.

MS-TuP2 A New Way to Get Steady Trichlorosilane (TCS) Vapor Flow for EPI Deposition Process*, A. Sidhwa,* ***Z. Lu****, S. Bansal,* STMicroelectronics, Inc*; C. Cross,* STMicroelectronics, Inc.

TCS has been used for many years as silicon source in high temperature EPI applications. It is still preferred in many applications since its low material cost and high deposition rate. In TCS EPI process, hydrogen (H2) is frequently used as carrier gas to convert TCS from liquid to vapor and carry TCS vapor to reaction chambers. The flow of TCS vapor is normally controlled by a Liquid Vapor Controller (LVC). It requires stable TCS liquid temperature to achieve good repeatability of TCS vapor flow. If both low and high TCS vapor flows are required, two LVCs have to be installed in parallel to achieve both low and high flow controls. A traditional LVC controls TCS vapor flow by measuring the mass difference between incoming gas (H2) and outgoing (H2+TCS) of the controller. It can provide steady TCS vapor flow if the temperature of TCS liquid is stable. Since TCS vapor pressure is extremely sensitive to TCS temperature, LVC can no longer provide steady TCS flows if TCS temperature fluctuates. The reason is that the temperature of outgoing gas (H2+TCS) and TCS partial pressure fluctuate according to the fluctuating TCS liquid temperature. In order to resolve the overhead/delay of TCS minibubbler/ conducting lines and their temperatures, a Piezocon flow controller was introduced and installed downstream of the TCS minibubbler. Since Piezocon controller calculates the accurate TCS flows in real time and its located downstream of the whole minibubbler unit, it becomes independent of the TCS liquid temperature. Piezocon controller also has high accuracy and repeatability in a wide range of vapor flows, which includes our low and high TCS applications. Once it combines with a digital MFC, which also has high repeatability in both low and high flow, the combination would provide us very steady TCS vapor flows in both low and high ranges.

MS-TuP3 The Evaluation of a Twin Wire Arc Spray (TWAS) Process for Coated Shields used in Soft-Sputter Etch Pre-Clean Chambers*, A. Sidhwa,** *M. Goulding, M. Kalaga, X. Breurec, R. Pierce, T. Gandy,* STMicroelectronics, Inc

A Soft Sputter Etch (SSE) process plays a vital role in the cleaning of contacts and vias prior to the deposition of contact barriers and via liners. This paper describes the work performed at STMicroelectronics to eliminate Silicon Oxide (SiO2) defects, which are observed at the end of the Pre-Clean chamber component (quartz and shield) lifetime; the latter is specified in RF hours. During the component re-cycling process, the aluminum (Al) RF shield receives a particular surface finish after the cleaning step. It is well known that the Bead-Blast/Post-Blast Etch (PBE) process produces a relatively rough surface finish, which enhances the oxide sticking properties during subsequent wafer sputter-etch. However during such processing, a large surface area of roughness (containing a small number of nucleation sites) is produced on the surface of the shield, resulting in defects (Silicon Oxide flakes) being observed at the end of the Pre-Clean chamber lifetime: i.e., the sputter-etched oxide becomes clustered around a comparatively small surface area, with continuous growth in a vertical direction producing "Worm" defects. The latter defects constitute "stress risers," which are a key source of oxide de-fragmentation. Hence, when trying to increase the sputter-etch chamber component lifetimes from the current 60 RF hours to a significantly higher value of 250 RF hours, the problem of Worm defects becomes more significant. However by contrast, an Al RF shield with a TWAS surface finish shows no similar issues at comparable lifetime. This paper describes the evaluation and implementation of TWAS for the Al RF shield, and explains the significant impact/elimination of Worm defects due to the change in the RF shield surface condition.

MS-TuP4 Two Gas Reactive Sputtering of Oxynitride Compounds: Model and Practice*, D.C. Carter,** *D.J. Christie, W.D. Sproul,* Advanced Energy Industries, Inc.

Reactive sputtering process control has been the subject of much research in recent years. The result of this work has been the development of methods for improving the economy and utility of this popular deposition method. Adding to the understanding of reactive sputtering techniques are functional models developed to explain the dynamics of these often difficult to control processes. Most common, both in practical use and in laboratory research have been deposition processes involving a single reactive gas producing simple binary compounds. Only in the past few years have models been extended to consider the effects of a second reactive gas. Similarly, practical understanding from empirical studies involving two reactive gasses is quite limited. The general rule recognized from models and laboratory experience holds that for the deposition of most compounds effective control in the transition region between the metallic condition and the poisoned condition requires some form of active, partial pressure or similar control. Adding a second reactive gas to the process adds great complexity to the control challenge. Carlsson et al.@super 1@ demonstrated that a two reactive gas process can exhibit a behavior called "trapping" where the sputtering target becomes trapped in a poisoned state. Only through the removal of both reactive gases would the model allow the target to recover from the poisoned state. Based on this the partial pressure of both reactive gases must be controlled to prevent the trapping behavior. We apply such control to a two reactive gas sputtering process, first in deriving solutions to mathematical models and then in practice. Using active, multi-gas control we demonstrate stable two gas reactive sputtering for the oxynitride systems of Silicon, Titanium and Aluminum and within the stable operating space we show film composition control allowing user specified film properties and performance. @FootnoteText@ 1. J. Vac. Sci. Technol., A 11(4), (1993).

MS-TuP5 Hard Mask Dual Damascene Integration Scheme for 65nm*, G.A. Delgadino,** *T.P. Pender, M. Le, S. Li, L.Q. Xia, Y. Ye,* Applied Materials, Inc.

Smaller geometries and the use of lower Îº dielectrics in BEOL integration at 65nm and beyond will require extensive changes in dual damascene integration scheme. Traditional via-first approach reaches its limits as 248nm photoresist is replaced by thinner, weaker, poisoning-prone 193nm photoresist. In this paper presents the development of a hard mask integration solution for extending the implementation of copper/low-Îº interconnect structures at 65nm node and beyond. The scheme overcomes major challenges in low-Îº integration, minimizing ashing damage to low-Îº material and avoiding photoresist poisoning issues associated with 193nm resist. Two Hard mask materials, TiN and W were investigated and potential problems addressed. For the etching point of view, both materials showed good performance but TiN required more tradeoffs due to its lower sputtering resistance and more chemically reactive nature. On the other hand, TiN transparency in part of the visible spectrum, facilitate integration while W required modifications during deposition and/or limitations on the mask thickness. Preliminary Low shear-force CMP with different slurries demonstrated good removal rates for both materials. From the perspective of feasibility and cost, hard mask Dual Damascene appears to be a promising candidate for competitive Copper/Low k integration.

MS-TuP6 Integration of an Ultra Low-k Dielectric in a 300mm 130nm Trench First Dual Damascene Etch Process*, **R. McGowan**, P.J. Wolf,* International Sematech*; D. Wang,* Tokyo Electron America, Inc.

This paper describes a two level metal, 130nm dual damascene etch process development, using an ultra low-k (ULK) dielectric material (k=2.2) on 300mm wafers. The process used a dual hardmask approach in a "Trench First" etch scheme with an interlayer etch stop. Each step requires good uniformity and selectivity to the underlying layers. A BARC etch DOE (used in all recipes) and correct selection of the hardmask & barrier etch chemistries were key factors in the successful etch development. Three iterations, in an overall cycle of improvement, are given as examples, used to take the process from an initial low yield to a robust high yielding process.

MS-TuP7 Effect of Double Polishing Pad on the Shallow Trench Isolation¬Chemical Mechanical Polishing (STI-CMP) Process*, Y.J. Seo, **S.W. Park**,* DAEBUL University, South Korea*; W.S. Lee,* Chosun University, South Korea*; S.Y. Kim,* Dongbu-Anam Semiconductor Co. Inc., South Korea

Chemical mechanical polishing (CMP) technology for global planarization of multi-level inter-connection structure has been widely studied for the next generation devices. CMP process is carrying out by pressing a rotating wafer against a moving polishing pad on which suitable slurry is dispensed. Among the consumable for CMP process, especially, polishing pad set and itâ?Ts material properties play a very important role into the removal rates and global planarization ability of CMP process. In this paper, we investigated the effects of different sets of polishing pad to apply the direct shallow trench isolation (STI)-CMP process using high selectivity slurry (HSS). As our preliminary experimental results, IC1000/JR111 pad set and IC1000/subaIV pad set have the highest selectivity. Even if selectivity is high, because IC1000/SubaIV set shows the low removal rate, we could conclude that IC1000/JR111 set is more superior than IC1000/SubaIV set. Also, the wafer map of hard pad set showed the center-fast type, and soft pad set showed the edge-fast type. Through the above results, we could select the optimum polishing pad set to achieve the direct STI-CMP process without reverse moat etch step, so we could expect the improvements of throughput, yield and stability in the ULSI fabrication process.

MS-TuP8 Effects of Slurry Temperature on the Oxide-CMP Performance*, W.S. Lee, **T.W. Kim**,* Chosun University, South Korea*; Y.J. Seo,* DAEBUL University, South Korea

The mechanical polishing pad and chemical slurry play an important role in chemical mechanical polishing (CMP) which has recently been recognized as the most effective method to achieve global planarization in ultra large scale integrated circuit multi-level interconnections. In this paper, we have investigated CMP performance of SiO2 as a function of different temperature of slurry and pad surface. There are two ways to study the temperature effect on CMP performance: (1) by controlling the temperature of both the pad and slurry at a desired value, or (2) by adjusting only the slurry temperature and keeping the polishing pad temperature. Moreover, the relationship between the removal rate (RR) and zeta-potential as a function of slurry temperature were investigated. According to the preliminary experimental results, it appears that the observed slurry temperature dependence of RR is mainly due to the change of pad surface mechanical property with the slurry temperature. Therefore, the understanding of these temperature effects provides a foundation to optimize an oxide CMP process for ULSI multi-level interconnection technology. This work was supported by a Korea Research Foundation grant (KRF-2002-005-D00011).

MS-TuP9 Impact of Reconditioned PVD Shielding on Process Yield*, D.J. Zuck, **G.H. Leggett**, D.S. Zuck,* QuantumClean

Process control is impacted by many variables in the chamber of a semiconductor process tool. Process chambers often have shielding that is removable and can be reprocessed for reuse. The effective reprocessing of this shielding can have a dramatic impact on process performance. The process deposition must be removed completely and additional contaminates can not be added to the shielding. The shielding is in close proximity to the wafer surface and often can transfer contaminates to the wafer. This shielding can include clamp rings which can contact the wafer in the edge ring exclusion area. The surface condition of this shielding must be maintained. The typical cleaning methodology for the removal of metal deposits from stainless steel shielding is corrosive and can attack the underlying base metal. Changes in surface morphology and finish can result in shorter lifetimes for parts and also have an impact on process yield. Particle contamination can result from shielding that does not have the proper surface morphology and/or surface preparation. A methodology was developed to monitor the surface condition and recondition the part when this surface morphology has deteriorated to a point where it has an impact on process yield. A method was further developed that reconditioned the surfaces and improved the lifetime of these parts. Data will be presented on the mobile ionic contamination of the parts as well as the surface finish and its impact on process performance. A comparison of surface finish with process performance will be described.

MS-TuP10 Silicon Isotope Enrichment by IRMPD of Si@sub 2@F@sub 6@: A Method for High-Efficiency Enrichment of @super 28@Si by Two-Color CO@sub 2@ Laser Irradiation*, **H. Ohba**, A. Yokoyama, M. Hashimoto, K. Katsumata, H. Akagi,* Japan Atomic Energy Research Institute, Japan*; S. Arai,* Hill Research Corporation, Japan

The natural abundance of silicon isotopes is 92.2% @super 28@Si, 4.7% @super 29@Si and 3.1% @super 30@Si. It has been reported that an isotopically pure @super 28@Si single crystal has a thermal conductivity about 60% higher than that of a natural silicon single crystal at room temperature. This pure material is expected to contribute to the creation of higher-density silicon integrated circuits. Laser isotope enrichment processes promise low energy inputs, low capital costs and lower tails assays, hence significant economic advantages. The infrared multiple photon dissociation (IRMPD) of Si@sub 2@F@sub 6@ leads to the formation of SiF@sub 4@ and SiF@sub 2@. The Si@sub 2@F@sub 6@ with enriched @super 28@Si can be obtained by dissociating the Si@sub 2@F@sub 6@ containing @super 29@Si and @super 30@Si selectively. In order to obtain highly enriched @super 28@Si products in the case of a conventional one-color CO@sub 2@ laser irradiation, however, a high fluence and a large number of laser shot are required, and it is unsuitable for large-scale separation. So, we have studied a rapid and highly efficient method for enrichment of silicon isotopes utilizing isotopically selective IRMPD of Si@sub 2@F@sub 6@ by a two-color laser irradiation scheme. We demonstrated that the dissociation rate of Si@sub 2@F@sub 6@ molecule per pulse increased about 10 times compared with the conventional one-color irradiation. And consequently we were able to acquire the highly enriched @super 28@Si at about one tenth of the laser shots required in the case of the conventional method.

MS-TuP11 Silicon Isotope Enrichment by IRMPD of Si@sub 2@F@sub 6@: Development of Continuous Silicon Isotope Enrichment Technique for Large-Scale Production*, **K. Katsumata**, H. Ohba,* Japan Atomic Energy Research Institute, Japan*; H. Akagi, A. Yokoyama,* Japan Atomic Energy Research Institute*; S. Arai,* Hill Research Corporation, Japan

Since it had been reported that an isotopically pure @super 28@Si single crystal has high thermal conductivity, it has been growing interests in its use to the high thermal conductive semiconductor substrate. For the expansion of the market of the enriched silicon, it may be necessary to develop a large-scale silicon isotope enrichment method. We have demonstrated a highly efficient silicon isotope enrichment utilizing infrared multiphoton dissociation (IRMPD) of Si@sub 2@F@sub 6@ irradiated with two-color CO@sub 2@ laser@footnote 1@. The scheme consists of two successive steps: At first, the Si@sub 2@F@sub 6@ molecules containing @super 29@Si and @super 30@Si are excited selectively by the irradiation at nearly resonant wavelength with weak pulsed laser beam. Then, the excited molecules are dissociated by the irradiation at non-resonant wavelength with relatively high intense pulsed laser beam. In this report, we developed continuous silicon isotope enrichment technique for the large-scale production, based on this method. An apparatus for continuous isotope enrichment consists of two TEA-CO@sub 2@ lasers, a reaction cell with a gas flow system, and instruments for the monitoring of the abundance of Si in Si@sub 2@F@sub 6@ and the production rate. Si@sub 2@F@sub 6@ gas and buffer Ar gas flowed through a reaction cell with controlling pressure and flow rate. Then isotopically selective IRMPD of Si@sub 2@F@sub 6@ molecules containing @super 29@Si and @super 30@Si were done in the reaction cell by the simultaneous irradiation with two laser pulses at different wavelengths. All of the reaction products were corrected in a trap at 77 K. After the conditions for continuous isotope enrichment had been optimized, @super 28@Si enriched up to 99 % was produced at a rate of 0.7 g/h with the yield of 63 %. @FootnoteText@ @footnote 1@A. Yokoyama, et al., US patent 2003-0034243 A1 (2002).

MS-TuP12 Field Emission Enhanced Semiconductor Thermoelectric Cooler, ***B.L. Weiss***, *P.H. Cutler, N.M. Miskovsky,* The Pennsylvania State University*; M. Chung,* University of Ulsan, South Korea*; N. Kumar,* UHV Technologies

We report the initial experimental results of the fabrication and measurements of a prototype field emission enhanced thermoelectric cooler device. The device is designed for applications in microelectronics, and operating from ambient to cryogenic temperatures. The device is fabricated using CVD deposited wide band gap (diamond and III-V nitrides) thin films. Cooling measurements are carried out in a UHV system using both thermocouple and optical thermometry. This work is motivated by a recent theoretical analysis of an efficient, compact, low power consumption thermoelectric cooler by Chung et. al. @footnote 1@. The new paradigm involves cooling via electron field emission from wide band gap materials which is based on a corrected theory@footnote 2@ of the Nottingham effect @footnote 3@ with calculated cooling rates of up to 100 W/cm@super 2@ or better. The thermoelectric cooler device proposed here uses an electric field modulated current to transport energy (i.e., heat) from a cold source to a hot source via n- and p-type carriers. This device is fabricated by combining the standard n- and p-channel solid-state thermoelectric cooler with a two-element vacuum field emission device inserted into each of the two channels which introduces an essentially infinite thermal resistance for lattice heat conduction. In the proposed cooler, the heat removed from the cold source is the average energy difference of the field emitted electrons from the n-type and p-type semiconductors. The theory predicts the average energy removed (cooling rate) increases with decreasing doping concentration and with increasing local field at the emitter surface. With typical values of doping and field, the cooling rates exceed those of standard thermoelectric coolers. The cooling device is shown to have an energy transport (i.e., heat) per electron of up to 500 meV depending on concentration and field while, in good thermoelectric coolers, it is about 50-60 meV at room temperature.} $Footnotes {@footnote 1@ Moon Chung, P.H. Cutler, N.M. Miskovsky, Nalin Kumar and V. Patel,Solid-State Electronics, 47 1745-1751, 2003. @footnote 2@ Moon Chung, P.H. Cutler, N.M. Miskovsky and T.E. Sullivan,J Vac Sci Technol B;12(2),727-36, 1994. @footnote 3@ W.B. Nottingham Phys. Rev, 59, 907, 1941.

Applied Surface Science
Room 210A - Session AS-WeM
Chemometric Analysis of Spectral or Image Data; XPS/TOF-SIMS Applications
Moderator: J.E. Fulghum, The University of New Mexico

8:20am **AS-WeM1 Angle-resolved X-ray Photoelectron Imaging of Heterogeneous Polymer Samples***, **K. Artyushkova**, J.E. Fulghum,* The University of New Mexico

ARXPS has been widely used for thickness calculations, discerning molecular orientation, and estimating both surface enrichment and concentration gradients. For multicomponent heterogeneous samples not only the average concentration but morphology and chemical heterogeneity are important. In this work we demonstrate the results of combining ARXPS and imaging for analysis of polymer blend samples. Challenges in combining the two approaches include locating the same area for image acquisition at multiple take-off angles, the small depth of focus in imaging mode, and the geometrical transformation of images with changing take-off angle. The conversion of the original photoelectron images to a volume representing the top 3-10 nm of the polymer blend includes principal component analysis, spatial image transformation to correct for geometry or image warping, automatic image registration, mapping images to concentration with the assistance of AR small area spectroscopy, image morphing and visualization. AR images were used to create volumes from the top 3-10 nm of blends of polyvinylchloride (PVC) and polymethylmethacrylate (PMMA) or polystyrene (PS). These volumes allow for the visualization and estimation of the degree of surface segregation and separation of polymer phases. This work has been partially supported by NSF CHE-0113724.

8:40am **AS-WeM2 Detection of Small Chemical Changes on Liquid Crystal-Aligning Polymer Surfaces using Multivariate Data Analysis of XPS Spectra***, **S. Pylypenko**, K. Artyushkova, J.E. Fulghum,* The University of New Mexico

Ion beam alignment of liquid crystals is one of several non-contact methods under investigation as a substitute for mechanical rubbing. The characterization of Ar+ ion beam modified polymers is required in order to understand the macroscopic and microscopic alignment mechanisms. Polymer alignment layers, including polyimide and polystyrene, were studied using X-ray Photoelectron Spectroscopy (XPS) to characterize chemical changes and the surface anisotropy of the alignment substrate. XPS spectra were acquired from samples before and after bombardment, after exposure to the atmosphere, and after 90 degree rotations. XPS spectra of the polymers are dominated by changes resulting from Ar+ ion beam exposure, but also contain smaller changes related to chemical anisotropy. The effect of surface oxidation resulting from the high reactivity of the polymer surfaces after bombardment also must be taken into consideration when interpreting the spectra. We used multivariate analysis to differentiate between chemical changes from ion beam bombardment and oxidation versus the small changes due to chemical anisotropy created by the ion bombardment. Spectra manipulation, including subtraction, and multivariate analysis using Principal Component Analysis (PCA) and Multivariate Curve Resolution (MCR) allowed us to extract information about small changes due to chemical anisotropy. The anisotropy, and associated liquid crystal alignment, result from selective destruction of the weakest bonds relative to the direction of ion beam bombardment.

9:00am **AS-WeM3 Identifying Surface Chemical Changes with XPS Spectral Imaging and Multivariate Statistical Analysis@footnote 1@***, **D.E. Peebles**, J.A. Ohlhausen, K.R. Zavadil, M.R. Keenan, P.G. Kotula,* Sandia National Laboratories

Imaging X-ray Photoelectron Spectroscopy (XPS) allows the distribution of elements and chemical states to be mapped across a surface region of interest. Conventional use of XPS mapping involves utilizing images acquired at peak intensities for chemical species of interest with the subtraction of a suitable background image off the peak. Both peak and background image energies need to be determined from a prior spectrum taken from the imaged region to insure optimal energy selection. While this allows differentiation of chemical states, image contrast and resolution may be poor, especially for overlapping spectral peaks. A more complete and definitive picture of the distribution of chemical species across the surface may be obtained by acquiring a series of images over an energy range that covers the peaks of interest. This generates a very large amount of data that must be processed and correlated, generally with some form of multivariate statistical analysis. Many types of multivariate statistical analyses require user input for the number of species present and their general lineshape. Others produce non-physical spectra that may be difficult to interpret. Multivariate statistical analysis methods developed at Sandia National Laboratories facilitate the rapid analysis of the large quantities of data produced by spectral imaging in an efficient manner without user bias or input. The use of these methods for XPS spectral images to detect changes in chemical state will be demonstrated. In particular, examples illustrating the ability of these techniques to resolve overlapping peaks and reveal correlated species will be included. @FootnoteText@ @footnote 1@ This work was completed at Sandia National Laboratories, a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

9:20am **AS-WeM4 Algorithm for Improved XPS-Imaging***, **S. Tougaard**,* University of Southern Denmark, Denmark

Non-destructive XPS-imaging of surfaces is based on analysis of peak intensities. It is however well known that XPS-quantification from the peak intensity leads to huge uncertainties because the measured intensity depends strongly on the depth distribution of atoms. The problem was basically solved by developing models for the detailed analysis of the energy distribution of emitted electrons leading to algorithms summarized in.@footnote 1@ The validity of these algorithms have been extensively tested experimentally and found to be able to accurately determine both the quantitative amount of atoms as well as their in-depth distribution within the outermost ~ 5-10 nm of surfaces. Practical application of these algorithms has increased after ready to use software packages were made available and they are now used in labs worldwide. These software packages are easy to use but they need operator interaction. They are not well suited for automatic data processing and there is a need for simplified strategies that can be automated and used in e.g. XPS-imaging where the huge amount of data hinders manual data analysis. In this paper we study a very simple algorithm that automatically takes the XPS-peak attenuation effect into account@footnote 2@. The algorithm is less accurate than those in@footnote 1@ but it is substantially more accurate than using peak intensities and it is well suited for automation. It gives the amount of atoms within the outermost ~ 3IMFP with a good accuracy and it gives also a rough estimate for the in-depth profile. In the talk, the validity of the simple algorithm is tested on several experimental systems and the results are compared to analysis of the same samples quantified by more accurate methods. The algorithm seems promising for significant improvements in XPS-imaging. @FootnoteText@ @footnote 1@ S. Tougaard, J. Vac. Sci. Technol. A14, 1415 (1996); see also www.quases.com@footnote 2@ S. Tougaard, J. Vac. Sci. Technol. A21, 1081 (2003).

9:40am **AS-WeM5 Chemometric Techniques for Two-way, Three-way and Higher-order Image Data***, **J.M. Shaver**,* Eigenvector Research, Inc., US*; B.M. Wise,* Eigenvector Research, Inc. **INVITED**

Historically, analytical instrumentation would measure a single response such as intensity or counts as a function of a single parameter such as incident energy (e.g. a spectrum). When this response is measured for a range of samples, one obtains "two-way" data. Each sample gives a single vector of responses. A wide variety of numerical analysis techniques exist for performing quantitative and qualitative analyses of two-way data. However, an increasing number of instruments measure response as a function of multiple parameters such as position on the sample, incident energy, and energy of response. Add to these the measurement of multiple samples and the data can become quite complex with respect to relationships between parameters. One method of analyzing such data is to focus on only one parameter at a time (sample vs. incident intensity) or, alternatively, to ignore the relationship between parameters and string the data into one long series of responses per sample. An more sophisticated approach arranges the data into a multi-way array which can be analyzed for relationships between controlled parameters as a function of sample. This often allows improved accuracy and specificity and, in some cases, is even easier to analyze because of the interrelationships. This paper will discuss the concept of multi-way data and some of the issues associated with its analysis, with particular note to multi-way spectroscopic images.

10:20am **AS-WeM7 Maximum Likelihood Principal Component Analysis of ToF-SIMS Spectral Images***, **M.R. Keenan**,* Sandia National Laboratories

Many modern surface analytical instruments are able to acquire huge amounts of data in the form of spectral images. ToF-SIMS, for instance, can easily generate a complete mass spectrum at each point in a 2D or 3D spatial array. The challenge for the data analyst, then, is to garner the analytically useful information from the overwhelming quantity of raw spectral data. Factor analysis techniques such as Principal Component Analysis (PCA) have proven quite useful in this endeavor. Standard PCA, however, assumes that noise in the data is uniform, that is, that it does not depend on the magnitude of signal. This is clearly not correct for methods that rely on particle counting where the noise is governed by Poisson statistics. In this case, properly accounting for heteroscedasticity is essential to extracting the chemical information into a minimum number of factors while maximally excluding noise. Maximum Likelihood PCA (MLPCA) is one approach to addressing this issue. MLPCA can, in principle, incorporate a separate uncertainty estimate for each individual observation in a data set. This paper will present a MLPCA analysis of a simple and intuitive ToF-SIMS spectral image. The results show that there is a tradeoff between the number of uncertainty parameters included in the model and the quality of each and, in fact, using poor estimates may be worse than doing nothing at all. The best results were obtained by using a low-rank approximation to the noise rather than individual estimates. MLPCA will also be compared with an optimal scaling approach. For the particular example given, the added benefits of MLPCA probably do not outweigh the greatly increased computational demands of the technique. This work was completed at Sandia National Laboratories, a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

10:40am **AS-WeM8 AXSIA Analysis of TOF-SIMS Spectral and Image Series Data@footnote 1@***, **J.A. Ohlhausen**, K.R. Zavadil, R.D. Kilgo,* Sandia National Laboratories

AXSIA (Automated eXpert Spectral Image Analysis), a patented multivariate approach invented at Sandia National Laboratories, is used to provide comprehensive analysis of spectral series and spectral image series. We directly compare spectra from many different samples (spectral series) and compare spectral images from different specimens or locations (spectral image series) using this statistical approach. This method of analysis provides full spectral separation of distinct components present within the system of interest. Component variation is expected with fragmentation changes resulting from aging, contamination, concentration, molecular orientation, and chemical reaction. We use spectral series analysis to understand how component variation might be impacted by monolayer deposition and coverage. Spectral series analysis with AXSIA shows promise in extracting a more quantitative determination of the effect of saturation coverage and molecular orientation on fragmentation patterns. We have also been able to process large, complex image datasets containing a number of analysis areas at once. By using a technique of merging multiple datasets into one large dataset, a direct comparison of analysis locations is made. The relative amount of contaminant and substrate species as a function of handling and processing conditions are determined. The effects of processing and handling are readily extracted in this chemical system because all data is processed at once. As a result, the information contained in the component analysis is complete and comprehensive. @FootnoteText@ @footnote 1@This work was completed at Sandia National Laboratories, a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

11:00am **AS-WeM9 ToF-SIMS as an Important Tool for Fuel Characterization: A Chemometrics Study***, **G. Jiang**, D. Stone, L. Baxter,* Brigham Young University*; B.J. Tyler,* University of Utah*; M.R. Linford,* Brigham Young University

The combustion of coal and biomass provides a significant amount of the energy needs of the world. As expected, there is a series of standardized tests for characterizing these materials. However, these time-consuming analytical methods do not generally provide the chemical information that is necessary to predict and better understand important problems such as NO formation and soot production. Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS) is one of the most powerful surface analytical methods in existence. Here we investigate the possibility of using a single ToF-SIMS analysis to characterize coal and biomass as a replacement for many of the tests that currently need to be performed on each sample. But more importantly we look to ToF-SIMS as a tool that can provide data that is rich in chemical information. To handle the enormous quantities of data that are produced by ToF-SIMS it has become increasingly common to use chemometrics methods such as PCA, PLS, and cluster analysis. Here we report a chemometrics study of ToF-SIMS spectra of a series of coal and biomass samples. As expected, PCA of ToF-SIMS spectra of coal and biomass show these classes of materials to be distinctly different. In particular, scores and loadings plots of coal and biomass ToF-SIMS spectra show that the coal spectra are dominated by inorganic ions, while the biomass spectra are dominated by organic ions. We also note that data preprocessing has a significant impact on the resulting PCA, where more information appears to be available from the data when normalization and standardization are applied. PLS of biomass data shows excellent agreement between the nitrogen content of these fuels and the ToF-SIMS spectra. In summary, these multivariate analyses help build the case for ToF-SIMS as a useful and powerful tool for fuel analysis.

11:20am **AS-WeM10 A Chemometrics Analysis of ToF-SIMS Spectra of Monolayers on Scribed Silicon***, **L. Yang**, Y.-Y. Lua, G. Jiang, M.R. Linford,* Brigham Young University

While chemomechanical modification of silicon with a variety of reagents is now well established, a significant amount of physical characterization remains to be performed on these new monolayers to understand their structures. Time-of-Flight Secondary Ion Mass (ToF-SIMS) was performed on monolayers on scribed silicon derived from 1-alkenes, 1-alkynes, 1-holoalkanes, aldehydes and acid chlorides. In order to best analyze the vast quantity of data that is produced by SIMS a chemometrics analysis was performed. Principle component analysis (PCA) proved to be a powerful tool for data compression and information extraction. Nine different PCA analyses were performed, including analyses of i) negative, ii) positive, and iii) combination of the negative and positive spectra, using i) normalized data, ii) normalized and mean-centered data, and iii) normalized and standardized data. If only normalization is performed the first PC loses most of its information content, as it mostly relates to the distance between the spectra (plotted as single points in a hyperspace) and the origin. If both normalization and standardization are performed it is difficult to extract information from the data because too much noise is given equal importance with the data. The positive and negative ion spectra contain complementary information. PCA of negative ion spectra gave a good separation of the monolayers according to the types of adsorbates used in monolayer preparation. PCA of positive ion spectra primarily separated the monolayers according to the number of carbons in their precursor. PCA of the combined positive and negative ion spectra is similar to that of negative spectra. Loadings plots showed the variables that best account for the variability in the data. PCA also indicates the presence of a few outliers in a large set of data, which further shows the usefulness of this method for demonstrating and confirming surface quality. The results of this study are an excellent confirmation of monolayer formation on scribed silicon from a series of different precursor molecules.

Manufacturing Science and Technology
Room 303B - Session MS-WeM

Semiconductor Manufacturing Technologies for the 45nm Crisis

Moderator: L. Larson, Sematech

8:20am **MS-WeM1 Integration Challenges for 45nm Strained Si Devices***, **M. Sadaka**, A. Thean, A. Barr, T. White, B. Nguyen, V. Vartanian, M. Zavala, D. Eades, S. Zollner, Q. Xie, X. Wang, R. Liu, M. Kottke,* Freescale Semiconductor **INVITED**

As power supply voltage becomes lower with successive scaling, the non-scalability of threshold-voltage and conventional gate oxide to maintain low stand-by leakage is rapidly reducing the maximum gate overdrive factor. Enhancing carrier mobility by biaxially-straining Si on relaxed SiGe on SOI and on Bulk substrates provides a viable option to sustain the continual drive current increase. Though strained-Si addition to conventional MOSFET seems minimally disruptive, the use of SiGe in CMOS devices introduces new process and device challenges, wafer quality requirements, substrate cost issues, and new metrology requirements for strain monitoring. All these challenges need to be addressed in order to prove successful manufacturability. This talk will focus on the integration challenges of strained Si devices. The process and device challenges include Ge up-diffusion into strained Si channel, dopant diffusion differences between Si and SiGe, NiSi versus CoSi, and the need for raised source drains (formed by selective epitaxy) due to Ge segregation with cobalt silicidation. Wafer quality requirements include reducing the defect density less than 10@super 3@ defects/cm@super 2@ in order to realize yielding, high density large circuits, while maintaining maximum levels of achievable strain at a reduced wafer cost relative to the cost of SOI wafers. Finally, the appropriate metrology specific to strained Si monitoring will be discussed.

9:00am **MS-WeM3 45nm Node Architecture: The Driving Force of the Ion Implantation and Activation Processes Challenges***, **D. Lenoble**,* STMicroelectronics **INVITED**

In the current development of the 65nm node, various technical approaches regarding doping processes have been evaluated to fulfill the technology requirements of poly-gate doping, ultra-shallow junctions, channel and isolation architectures and deep gradual junctions. Low thermal budget processes (solid-phase epitaxy), advanced ion implantation processes (Plasma Doping), advanced activation processes (flash or laser annealing), stressed SiGe junctions, Poly-SiGe gate, offset spacers, 0° tilt wells implants, antimony implants, etc. are some examples of processes that are evaluated by ICMs for the 65nm node. In this paper, we propose to make a review and to discuss each technique to highlight their specific benefits and drawbacks for the manufacturing of a planar 65nm technology platform. Based on this status and on the basic requirements of the 45nm node, we build different scenarios about the major technological or architectural breaks that will emerge. Then, such projections are discussed in term of future technical challenges for the ion implantation and activation processes.

9:40am **MS-WeM5 Taking SOI and Low-k Dielectrics Into 130nm and 90nm High-Volume Microprocessor Production: Challenges, Processes, Extendibility***, **R. Stephan**, D. Greenlaw, G. Burbach, T. Feudel, F. Feustel, K. Frohberg, F. Graetsch, G. Grasshoff, C. Hartig, T. Heller, K. Hempel, M. Horstmann, P. Huebler, R. Kirsch, S. Kruegel, E. Langer, K. Romero, H. Ruelke, H. Schuehrer, A. Wei, T. Werner, K. Wieczorek,* Advanced Micro Devices, AMD Saxony LLC, Germany **INVITED**

SOI and Low-k technologies are mature at AMD and run in high-volume production. These technologies were developed for the fabrication of the 9-metal AMD OpteronTM and AthlonTM64 microprocessors.@footnote 1@ The 130nm version has been in production for 18 months, and the 90nm product shipments began several months ago. The paper highlights several challenges found when moving from development to high-volume production. SOI process modules have been developed to support a smooth conversion from 130nm to 90nm. Basic learning can be applied for the extension to the 65nm node. Examples of advanced SOI process modules such as STI, ultra-thin gate dielectrics, gate pattering, and the Cu interconnect using CVD-deposited low-k dielectric will be shown. The early implementation of SOI and low-k dielectrics into high-volume manufacturing will allow for the successful extension into the next process generations. @footnote 1@AMD, the AMD Arrow logo, AMD Athlon, AMD Opteron and combinations thereof are trademarks of Advanced Micro Devices, Inc.

10:20am **MS-WeM7 Beyond Planar Bulk CMOS: Manufacturing Issues in the 3rd Dimension***, **C.R. Cleavelin**,* Texas Instruments **INVITED**

The continuation of highly scaled Planar Bulk CMOS has been identified @footnote1@ as very difficult, if not impossible, at or beyond the 45nm Node due to short channel effects (SCE) and other parasitic effects. Several device structure options for "non-classical" CMOS have been proposed and fabricated in research environments, e.g., Ultra-Thin Body SOI (UTB-SOI) or Multiple-Gate FET (MuGFET) both using lightly doped bodies for scaling gate length Lg well below 20nm. Although these devices offer good device characteristics and scaling opportunities, fabrication and optimization of these devices for device level CMOS integration and production present inherently difficult challenges. This talk will identify and discuss many of these integration roadblocks and manufacturing challenges and discuss possible paths to overcome them. @FootnoteText@ @footnote 1@ International Technology Roadmap for Semiconductors 2003 Edition.

11:00am **MS-WeM9 The Nanotechnology Research Institute***, **G. Bourianoff**,* Intel Corp. **INVITED**

The Semiconductor Industry Association (SIA) has recently called for the creation of the Nanotechnology Research Institute (NRI) which will be dedicated to creating new ideas and demonstrating feasibility for novel electronic switching devices with associated memory and interconnects by the year 2020. The proposed institute will be a joint effort by industry, academia and government involving university faculty and students working with industrial assignees working in state of the art facilities located on or adjacent to university campuses. Funding would come from a partnership between government and industry. This paper will give the latest information on the research program and organizational structure of the NRI. In general, the NRI will address the scientific and engineering aspects of classical information processing at nanometer scale lengths, fempto second time scales and atto Joule energies. It will consider devices and architectures that rely on state variables other than electronic charge such as spin, phase, photons, dipole orientation, magnetic flux quanta, orbital symmetries and other non-stander state variables. It will consider novel architectures that rely on nearest neighbor data flows and novel data representations that may rely on associative data structures. It will seek to understand the relationship between information and entropy and many other advanced concepts that are vital to future scaling.

Manufacturing Science and Technology
Room 303B - Session MS+AS-WeA

Non-Destructive Analysis and Metrology for Advanced Manufacturing

Moderator: A. Testoni, Varian Semiconductor Equipment

2:00pm **MS+AS-WeA1 Advances in X-ray Reflectivity (XRR) and X-ray Fluorescence (XRF) Measurements Provide Unique Advantages for Barrier and Metal Layer Measurements of 65 nm Node Devices***, J.S. Spear,* Technos International*; H. Murakami, **S. Terada**,* Technos Company Limited, Japan

We have developed a thin-film metrology tool that fulfills the metrology requirements for the production of 65nm node technology and beyond. This tool combines X-ray Reflectivity (XRR) and X-ray Fluorescence (XRF) measurements to provide accurate, high throughput, measurements. Improvements in both the XRR and XRF configurations were made to allow high throughput measurements on films as thin as 0.5 nm. One of the challenges for the 65nm node is measuring the Cu metal layers and their accompanying barrier layers. The difficulty in measuring these layers is increased since the barrier is often a bi-layer composed of both TaN and Ta. This paper describes how a combined XRR XRF tool can be used to accurately measure these individual layers with optimum throughput.

2:20pm **MS+AS-WeA2 Non-Destructive Ultra-Thin Film (0-100A) Analysis in the Lab and the Fab.***, **C.R. Brundle**,* C. R. Brundle and Associates **INVITED**

Whether for characterization or failure analysis work in the support laboratory, or for rapid quality control/metrology in a wafer processing fab, the need for analytical techniques capable of determining thickness, composition, and composition as a function of depth (including differences at interfaces) is increasing as the variety of film material used in processing expands, and as films and stacks get thinner. The current materials roster, and the stringency of analytical requirements are briefly reviewed, then four non-destructive techniques being deployed in lab and fab situations are discussed and their capabilities compared for these two different environments. They are X-Ray Fluorescence, XRF; X-Ray Reflectivity, XRR; X-Ray Photoelectron Spectroscopy, (XPS and angle resolved XPS); and Low Energy X-Ray Emission spectroscopy, LEXES.

3:00pm **MS+AS-WeA4 Crystalline Structure and Stress Characterization in Thin Films by Means of Optical Spectroscopy***, **G. Conti**, Y. Uritsky,* Applied Materials, Inc.

Nondestructive characterization techniques are crucially important in developing new materials. Raman Spectroscopy is a powerful and versatile tool. Its capabilities range from structural identification and conformation of molecules, to identification of crystalline structure of materials. This power and versatility has led to its progressively more extensive applications to semiconductor industry as an analytical tool. In this paper we present some applications of Raman analysis to the characterization of thin films. The present challenge in thin films characterization is on one hand the determination of the film composition and/or crystalline phase; on the other the stress to which the film is subjected as it is deposited under different temperatures, chemical conditions of depositions, and substrates. In the first part, we report on the Raman characterization of silicides films generated on a Si surface. In particular we determine the stoichiometric composition of the silicides, their crystalline phase and their thickness. In the second part, we determine the stress of Si deposited on SiGe. The main advantage of Raman versus conventional X-ray diffraction is the ability to measure strain in thin layers (from 5 nm and above). We show here that Raman is the ideal method for characterizing strained cap Si layers with critical thickness in the range of 100-200 Å., and for characterizing stresses in quantum wires, quantum dots and other hetero-structures, which are becoming more and more important for fabricating devices with enhanced performance.

3:20pm **MS+AS-WeA5 Optical Properties (IR to VUV) and Birefringence of Graphite-like Amorphous Carbon***, **S. Zollner**, R. Liu, R.B. Gregory, W. Qin, J. Kulik, N.V. Edwards, K. Junker,* Motorola*; T.E. Tiwald,* J.A. Woollam Co.

Amorphous carbon films of 50 nm thickness, low surface roughness, and low densities (1.5-1.7 g/cm@super 3@) were deposited on Si using plasma-enhanced chemical vapor deposition (PECVD) between 300 and 550°C. With increasing deposition temperature, the hydrogen content (determined with elastic recoil detection) is reduced from 35% to 15%. For films grown at lower temperatures, ellipsometry data (0.7 to 9.5 eV photon-energy range, taken at 35-75° angle of incidence on a rotating-analyzer ellipsometer with a computer-controlled Berek waveplate) can be fitted very well by a single optically isotropic layer with low visible absorption (@epsilon@@sub 2@1 Torr), the ion energy is expected to be very low, which leads to dominant sp@super 2@ character of our films@footnote 1@ (verified by electron energy loss spectrometry) and low density (

3:40pm **MS+AS-WeA6 Metrology for Advanced Manufacturing***, **M.I. Current**,* Frontier Semiconductor **INVITED**

Metrology for process controls for manufacturing of advanced semiconductor devices faces an unprecedented number of challenges, well beyond the continued scaling to smaller transistors and denser functional arrays. Some common themes are the sharp increase in the introduction of new materials, new materials combination and interfaces and new device structures. This review will consider the metrology challenges and some new methods in four areas: (1) ultra-shallow doped junctions, including dopant activation and leakage currents, (2) stress and adhesion characteristics of metal/dielectric interfaces for gate and interconnect stacks, (3) local strain characterization of isolation structures, gates and channels as well as wafer-scale, strained materials systems and (4) bonding and layer transfer methods for integration of heterogeneous materials and devices such as, multi-level SOI wafers for logic, memory and photonic devices, 3-D packaging of functionally diverse devices and integration of MEMS/photonic structures with CMOS devices.

4:20pm **MS+AS-WeA8 Total Analysis of the Gases in Semiconductor Manufacturing Process: Use of Ion Attachment Mass Spectrometry***, **M. Nakamura**, Y. Taneda, Y. Hirano, Y. Shiokawa,* ANELVA Technix Corporation, Japan*; M. Takayanagi, M. Nakata,* Tokyo University of Agriculture and Technology, Japan

Ion attachment mass spectrometry (IAMS)@footnote 1@ is a powerful tool to monitor semiconductor manufacturing process@footnote 2-3@ by analyzing the molecules in the gas because with IAMS fragment-free mass spectra can be obtained; i.e. only quasi-molecular ions without being suffered by dissociation are observed. The fragment-free detection is impossible with other ionization techniques such as the electron ionization. There are two-type equipments of IAMS; one for the process at the pressure from 100 Pa to atmospheric pressure, and the other for the process at several Pa. We analyzed the process for manufacturing semiconductor by measuring mass spectra of gases in the reaction chamber and of the exhaust gas simultaneously with these equipments. Very high frequency capacitively coupled plasma (VHF-CCP) (60 MHz, 1000 W) was produced in the reaction chamber by providing 2 Pa of Ar/c-C@sub 4@F@sub 8@/O@sub 2@ (100, 2, and 6 sccm, respectively). The equipment for gases at several Pa was installed on the sidewall of the reaction chamber with a connection pipe of 100-mm length. At the same time the exhaust gas from the reaction chamber was analyzed after the rough pump with the other IAMS equipment. Polymerized compounds such as carbonyl fluoloride (C@sub 4@OF@sub 8@, C@sub 5@OF@sub 10@, and so on) and other compounds were found not only in the exhaust gas@footnote 2@ but also in the reaction chamber. The kinds of compounds in the exhaust gas are less than those at the reaction chamber, suggesting the dissociation and the polymerization at the pumping line. We present in our talk about c-C@sub 4@F@sub 8@ plasma in other conditions, SiH@sub 4@ plasma, and other processes to show the applicability of IAMS. The authors are grateful to Dr. H. Ito et al. of ASET for their support to the experiments. @FootnoteText@ 1 T. Fujii, Mass Spectrom. Rev. 19, 111 (2000). 2 M. Nakamura et al., J. Vac. Sci. Technol. A 19, 1105(2001). 3 Y. Shiokawa et al., AVS Int. Sympo., PS-ThA1 (2003).

4:40pm **MS+AS-WeA9 Optimizing and Managing Calibration Gas Inventories to Address Accuracy, Analysis Shelf Life and the Cost of Ownership***, **P. Somssich**,* Osram Sylvania, Inc.

Today's analytical laboratories must meet ever-stricter quality controls and tracking requirements to maintain accreditation. Maintaining the usability of certified gas standards can be both time-consuming and costly. An ACCESS-based database was developed at Osram Sylvania Inc. to serve both cost management needs and the scientific requirements. The essentials of such a database required addressing critical issues: e.g., the shelf life of the certification, the traceability and cost of ownership. Almost 28 certified gas mixtures have since been recertified with initial fill and analysis dates going back 16 years. While some older mixtures were initially thought to be no longer useable, actual analysis results indicated that in most cases the vendor stated shelf life was far too short. However, there were a few dramatic exceptions. In addition to the costs associated with maintaining the certification, significant costs can occur by way of cylinder rentals, i.e., long term rental. This data is currently being evaluated to minimize the cost of ownership of the inventory, which includes 140 mixtures. The importance of good and accurate (or even very accurate) gas calibration standards has recently been highlighted by the use of EPA protocol gases associated with continuous emission monitors (CEMs). Since the Clean Air Act of 1990 makes the use of such monitors necessary, proper calibration standards and procedures can contribute to a sizeable financial windfall, while poor calibration can result in possible stiff penalties. Applications from lamp manufacturing will also be discussed showing a significant quality and financial benefit when lighting products are filled accurately resulting in optimal light output and performance as well as energy savings.

Manufacturing Science and Technology
Room 303B - Session MS-ThM

Advanced Process Control
Moderator: B. Van Eck, Sematech

8:40am **MS-ThM2 Fault Detection and Classification Using RGA in Semiconductor Manufacturing***, Y. Xu, J. Byrne, H. Clark, J. Parker,* IBM*; **J. Blessing**,* MKS

A new advanced residual gas analysis (RGA) system was jointly developed by IBM and MKS-Spectra and implemented in IBM's 300-mm wafer fabrication facility for the purpose of process monitoring and fault detection. The RGA system was integrated into the Computer Integrated Manufacturing (CIM) architecture using IBM's Advanced Process Control (APC) third party interface, an Extensible Markup Language (XML) based messaging system. The APC third party interface presents a brand new APC/sensor integration methodology allowing the RGA application (or any other sensor for this matter) to have access to both tool level event/trace/recipe data and fab level process/wafer information. A centralized database is used to manage the RGA system and to store summarized RGA data. Several examples will be offered to demonstrate how the role of the RGA system has expanded far beyond traditional photoresist detection and tool vacuum integrity. Its ability to quickly detect the undesirable process variations and incoming contaminations (photoresist or non-photoresist) proves to be critical to improving product yield, tool availability and ultimately the profitability of the fab. RGA fault classification is another important topic that will be covered. This classification is required to facilitate the proper handling of various RGA faults. One approach under consideration is to apply multi-variable analysis techniques to RGA data analysis. Some preliminary results will be given in the discussion.

9:00am **MS-ThM3 Using Process Control to Address Manufacturing Challenges at 300mm***, T.J. Sonderman, **C. Bode**,* AMD **INVITED**

The implementation of fully automated fab technologies will help ease the transition to 300mm manufacturing by making the most of the 300mm toolset capabilities. The transition to 300mm necessitates a level of process control improvement commensurate with the increase in the intrinsic value of the processed wafers. The key will be to keep these costs low while maximizing the value of each wafer. Part of the solution lies in establishing a fully automated system that allows for maximum predictability of output with manufacturing capabilities such as Advanced Process Control (APC). APC, a part of AMD’s Automated Precision Manufacturing (APM) technology, will be one of the key manufacturing technology that supports the transition. APC capabilities will need to evolve past lot-to-lot control to wafer-to-wafer control. 300mm tools will need to consider wafer-to-wafer control and extend the ability to change the process recipe for each individual wafer, in an automated fashion, as required. In addition, the control of individual processes will need to be integrated into a more holistic approach. This presentation will explore the evolution from unit process control to fab-wide automation. A holistic approach for factory automation goes beyond the optimization of performance within a given process or batch of wafers to focus on optimizing the output of the entire factory. The systems enabling optimization of process control are developed in coordination with advanced systems for automated yield analysis and production control. This integrated approach allows for a process control system that is both more flexible and more precise. Thomas Sonderman will discuss the manufacturing challenges that organizations face within 300mm and the benefits afforded to the market by moving to full automation. His presentation will draw on years of experience in the integration of these technologies to describe the essentials of a highly-automated 300mm manufacturing facility.

9:40am **MS-ThM5 Run-to-Run Process Control And Equipment Monitoring for Advanced Etch Applications.***, **J. Yamartino**, D. Mui, H. Sasano, W. Liu, M. Shen, J.P. Holland, V. Todorow, A.M. Paterson,* Applied Materials, Inc.

Run-to-run process control provides a means for significantly improving the process capability index of a process tool as well reducing cycle time of product wafers. The Applied Centura Transforma Etch system provides the capability for controlling and reducing wafer-to-wafer CD variations for critical etch processes including gate etch. These capabilities includes the ability to adjust multiple process parameters based on multiple inputs from either the Fab Host or integrated CD metrology for both feedforward and feedback applications. In addition, an analysis of etch chamber data from several Applied Materials Etch systems demonstrates the importance of monitoring the chamber data for stability and excursion control. A model of the chamber behavior is created using a multivariate analysis of chamber data taken under known good production conditions. This model is then used as a baseline to which subsequent runs are compared. Excursions are detected using an overall health index and classified in terms of the chamber variable or variables responsible for the excursion. The run-to-run monitoring functionality provides a powerful means for maintaining equipment uptime and reducing wafer scrap. Finally, run-to-run monitoring of chambers which are under feedforward/feedback control enhances the capabilities of advanced process control. Examples from production data demonstrate the important link between monitoring and control.

10:00am **MS-ThM6 Gate Sidewall Profile Control for Plasma Etch Tool***, **J. Tanaka**,* Hitachi Ltd., Japan*; A. Kagoshima, D. Shiraishi, H. Yamamoto, S. Ikuhara, M. Yoshigai,* Hitachi High Technologies Corporation, Japan

The scale of semiconductor devices has been shrinking year by year. Plasma etch tools have to meet demands for the tight control of gate critical dimensions (CD) for complementary metal oxide silicon (CMOS) devices. Although the hardware of plasma etch tools has been modified to stabilize the gate CD after the etch process, there remains slight wafer-to-wafer drift of the gate CD caused by the changing wall surface conditions. Run-to-run feedback control of the etch process is beginning to be used to eliminate the residual gate CD drift. To eliminate the gate CD drift by run-to-run control, we controlled the oxygen flow rate. Then we found the gate CD could not be controlled without changing the gate sidewall profile. To monitor the gate sidewall profile we used a CD scanning electron microscope (CDSEM). The CDSEM can measure a line width from the intensity profile of secondary electron. Thus it is natural that we should expect the intensity profile measured by the CDSEM to have a strong correlation with gate profile. We found the change in the gate sidewall profile can be monitored using the intensity profile of CDSEM. The etch process used for the experiment consists of four steps: a breakthrough step, a main etch step 1 (ME1), a main etch step 2 (ME2), and an over etch step. In our first trial experiment we controlled oxygen flow rate in ME2. Although the gate CD changed as expected, the gate sidewall was tapered to degrade its vertical shape. Thus we moved the control step to ME1. When we changed the oxygen flow rate in ME1, we could control the gate CD without changing the gate sidewall profile. Finally a gate CD drift in a lot was suppressed keeping the same gate sidewall profile.

10:20am **MS-ThM7 DRAM Gate CD Control in Dry Etch Process using Optical Integrated Metrology***, **Y.J. Jung**, Y.J. Kim, G.J. Min, C.J. Kang, H.K. Cho, J.-T. Moon,* Samsung Electronics Co., LTD., Korea*; J.W. Shon,* Lam Research Corporation

In current CMOS technology, a traditional sequence to obtain a target post etch CD is to perform lithography patterning and measure the CD in resist followed by dry etch and strip process. There is a specification for the CD in resist, which may result in target post etch CD. After the measurement of the CD in resist by using in-line scanning electron microscope (SEM), it is determined whether the rework process of lithography is necessary or not to meet the specification of the CD in resist. This kind of traditional CD control sequence, however, may be a source of following problems. First, since the measurement of the CD in resist cannot be performed for every lot as well as every single wafer due to throughput in mass production environment, it is not sure that all lots and/or wafers meet the specification of the CD in resist. Second, rework process for out of specification requires additional time, resources, and cost, which result in the decrease of productivity. Third, the measurement of the CD in resist using SEM causes CD slimming, which may give uncertainty error in CD determination. Although CD control in dry etch process using the optical integrated metrology is one of the promising candidates to overcome the above problems, it has not been applied in the DRAM Gate etch process due to the difficulty in thick Si@sub 3@N@sub 4@ hard mask. In this work, DRAM gate CD control in dry etch process is applied to sub-100 nm transistor fabrication. Gate etch of Si@sub 3@N@sub 4@ hard mask is performed using dual-frequency capacitively coupled plasma (DF-CCP) type etcher. After the CD in resist for each wafer is measured using the optical integrated metrology, the process controller determines a proper process condition to meet the target post etch CD according to the predetermined model of CD control with the measured CD in resist. Throughout this CD control in DRAM gate etch process, the variation of CD in resist (@>=@10nm) is reduced dramatically (@<=@2nm).

10:40am **MS-ThM8 Improving Etch Process Control with Advances in Vacuum Measurement***, J. Sipka, **S. Pewsey**, D. Leet,* Mykrolis Corporation

As each successive technology node is developed, staying the course of 'Moore's Law' has required device size scaling, and often, new materials development as well as tighter manufacturing process control, adherence to specifications and improved, tighter tolerances for chamber level devices. Process pressure repeatability at low mTorr setpoints is critical in obtaining the desired yields in Etch Processes. The process chamber pressure control system is a key component in achieving the process repeatability. At the heart of the chamber pressure control system is the Capacitance Diaphragm Gauge (CDG). If the fundamental vacuum measurement shifts or varies over time, the chamber pressure control sub-system will track this, resulting in changes in etch rate resulting in wafer lot to lot variability. A study was conducted to correlate (Etch) Process CD data with the (zero) stability of a new generation of Digital Process Vacuum Gauges. This paper will show test results of long term zero stability, process repeatability, and environmental sensitivity of a low-pressure heated digital capacitance diaphragm gauge under typical Semiconductor Etch conditions and under controlled test conditions. This paper will also address the causes of zero output shifts on Capacitance Diaphragm Gauges and design techniques utilized to minimize this effect.

11:00am **MS-ThM9 New Intelligent Molecular Flow Sensor-Experimental Definition of Flow Properties***, **H.S. Sagi**,* ATC, Inc.

A new Intelligent Molecular Flow Sensor (IMFS) enables, for the first time, direct gas flow measurements in the transitional and molecular flow regimes, as well as in the slip and continuum flow regimes, thereby enabling flow measurements at pressures ranging from vacuum through atmospheric. The properties of this sensor are investigated, along with the sensor's transitional operating ranges. The IMFS operates as a mass flow sensor (directly measures the mass flow) in the transitional and molecular flow regimes, and it operates as a volumetric flow sensor in the continuum and slip flow regimes. Understanding of these properties and ranges of operation are critical for demanding leak testing, sealed closure integrity testing and vacuum test applications.

Author Index

Bold page numbers indicate presenter