Tuesday Morning, October 26, 1999

Applied Surface Science Division
Room 6A - Session AS-TuM

Ion Beam Analysis and Depth Profiling
Moderator: F.A. Stevie, Lucent Technologies

8:20am **AS-TuM1 Characterization of Shallow Junctions Using Secondary Ion Mass Spectrometry**, ***C. Magee***, *I.M. Abdelrehim, T.H. Buyuklimanli, J.T. Marino, W. Ou,* Evans East **INVITED**

As design rules drop below 0.25um, there is a need for developing methodologies to form ultra-shallow junctions for the source and drain extension areas of FETs. Ultra-low energy ion implantation and plasma doping appear to be the leading candidates to form these junctions. However, these techniques need to be followed by some kind of annealing step to activate the dopant. This talk will show how SIMS can be used to characterize the as-implanted distributions for ultra-low energy implants of B, P and As, as well to characterize the degree of dopant diffusion that occurs during annealing. This will be prefaced by a discussion of the problems inherent in SIMS analysis of such shallow structures. These problems arise from atomic mixing from the primary ion beam and surface roughening during the analyses.

9:00am **AS-TuM3 Quantitative Determination of Oxide Layer Thickness and Nitrogen Profiles for Si Gate Oxides**, ***O. Brox,*** Universität Münster, Germany; *K. Iltgen,* AMD Saxony Manufacturing GmbH, Germany; *E. Niehuis,* ION-TOF GmbH, Germany; *A. Benninghoven,* Universität Münster, Germany

Accurate characterization of ultra-thin nitrided gate oxides is crucial for future semiconductor device scaling. We have investigated the capabilities of TOF-SIMS to control oxide thicknesses down to 2-3 nm and to quantify the nitrogen depth distribution. For all experiments we used the TOF III instrument, equipped with a flexible gas ion source and a cesium source (0.6 - 10 keV) for crater formation. An additional gas ion source (Ar@super@+, 11 keV) was applied for the analysis of the crater bottom. SiO@sub 2@ layer thicknesses can be determined by measuring exactly the position of the SiO@sub 2@/Si interface during depth profiling. This interface is indicated by drastic changes in the yield of the characteristic secondary ion species Si@sub x@O@sub y@@super -@. We found that the maximum in the Si- emission describes the position of the SiO@sub 2@/Si interface very exactly and that down to less than 3 nm oxide thickness a linear relationship exists between the position of this maximum and the oxide thickness as determined by TEM. We determined the nitrogen concentration in the oxide layers by following the nitrogen specific secondary ion SiN@super -@ and at the same time the SiO@sub n@@super -@ (n=0,1,2,3) intensities, which allow to calculate the corresponding lattice valency [1]. Relative sensitivity factors for nitrogen as a function of lattice valence were determined by using a nitrogen implant sample with a known nitrogen concentration. This allows to correct the measured SiN@super -@ profiles. We will report on these depth profiling results, the strong influence of the sputter ion energy on the width of the transient regime, changing between 1 nm for 0.4 keV and about 8 nm for 5 keV, on the influence of sample temperature during sputtering and on possible improvements by applying sputter ion energies @<=@ 0.4 keV combined with simultaneous Cs and noble gas sputtering. . @FootnoteText@ [1] C. Plog, L. Wiedmann, A. Benninghoven, Surf. Sci. 67 (1977) 565.

9:20am **AS-TuM4 Cesium Depth Profiling of Ultra-Shallow Implants**, ***E. Niehuis***, *T. Grehl, D. Lipinsky,* ION-TOF GmbH, Germany; *O. Brox, A. Benninghoven,* Universität Münster, Germany

Currently fabricated junction depths are between 50 nm and 100 nm, and they will decrease to about 10 nm for future deep sub-micron process technology. High depth resolution SIMS profiling is needed to control implant dose, junction depth, dopant distribution and its modification by thermal and chemical processes. In order to improve the depth resolution of SIMS, primary beam energies have been reduced over the last few years from several keV to a few hundred eV. In particular, oxygen depth profiling of B in Si in the sub-keV range has been studied in great detail over the last 2 years. In Cs depth profiling at low energies for the analysis of electronegative elements like As and P in Si two specific problems arise: 1. The decrease of the sputter yield with Cs energy results in a significant increase of the Cs surface concentration under steady state conditions. This has a strong influence on secondary ion emission and results in erosion rate changes in the transient regime. 2. A significant part of the implant dose is located in a native oxide or a screening oxide of the implantation process. Negative SI yields in a SiO@sub 2@ and Si matrix are quite different leading to errors in profile shape and implantation dose. We have investigated Cs sputtering at sub-keV energies using a TOF-SIMS instrument in the dual beam mode. A low energy Cs beam generates the sputter crater while a pulsed Ga beam at 15 keV energy probes the composition in the center of the crater. As the conditions of the analytical beam (energy, angle, spot size) are not changed with Cs beam energy, this dual beam mode is well suited for systematic studies in the very low energy regime. This paper will discuss the change of the positive and negative SI emission and erosion rate for SiO@sub 2@ and Si with Cs sputter energy. In addition, we investigate correction procedures in the transient regime and at the SiO@sub 2@/Si interface region.

9:40am **AS-TuM5 Characterization of Ultra-thin (2-3nm) Oxide Films using Low Energy Cs Ion Beams**, ***D.F. Reich***, *B.W. Schueler,* Physical Electronics; *J. Bennett,* Sematech, U.S.A

The thickness of silicon dioxide used as the transistor gate dielectric in most advanced memory and logic applications has decreased below 7nm, and is predicted to fall to 2-3nm for the next generation of devices. Characterization of thin oxide and nitrided oxide films by SIMS is currently achieved in quadrupole mass spectrometers using low energy primary Cs+ ions (0.75-2keV) at an angle of incidence of 60 degrees. Under these conditions, the preferred analysis method is to use MCs+ secondary ion monitoring in +SIMS, as this results in reduced matrix effects. For SIMS analysis of 2-3nm films, it is desirable to reduce the primary beam energy below 750eV, since the decay length and depth resolution even at this energy are comparable to the film thickness. Unlike the CsM+ results obtained with 0.75-2keV Cs+ beams at 60 degrees incidence, results with @<=@ 500eV Cs+ at angles from 60-75 degrees show matrix CsSi+ signals that are not in equilibrium in the near surface of the silicon substrate. By contrast, a 500eV Cs+ beam does result in constant matrix signals within the substrate when using ?SIMS. Interpretation of signals such as SiN- are, however, complicated by matrix effects at the oxide / silicon interface. The quadrupole SIMS instrument we are using employs ion columns with floating extractors. For the Cs column this results in useful primary beam currents of approximately 60nA at 500eV, and approximately 30nA at 250eV. Optimized off-axis extraction is possible using a split extractor when tilting the sample to vary the impact angle. To understand the CsM+ matrix signal variations at low primary energies, we report on measurements at Cs primary beam energies from 250-750eV, and at incidence angles of 60 and higher. Both +SIMS and -SIMS protocols are explored to understand optimum analytical conditions for characterization and quantification of 2-3nm ultra-thin oxides and oxynitrides.

10:00am **AS-TuM6 SIMS and XPS Correlation Study of Nitrided Gate Oxide**, ***C.A, Bradbury,*** Micron Technology Inc., US; *C. Blackmer,* Micron Technology Inc.

Reliability of dielectric films such as silicon dioxide in the gate has become a key issue as MOS devices shrink in size. Many of the problems associated with reduction in both the width and thickness of the gate oxide can be controlled with the addition of nitrogen. Nitrogen incorporation into the oxide has been shown to have significantly better charge trapping properties, less interface state generation, and more resistance to continued oxidation and incorporation of impurities. The nitrogen also acts as a barrier to diffusion of dopants from the silicon substrate. The amount of nitrogen present and its location in the oxide control the extent to which each of these properties is exhibited. The concentration and distribution of nitrogen in gate oxides was studied using Secondary Ion Mass Spectroscopy (SIMS) and X-ray Photoelectron Spectroscopy (XPS). The SIMS analysis used Cs ion bombardment and detection of the CsN+ cluster to reduce the matrix effects associated with profiling from silicon oxide into silicon. A procedure was developed for XPS to provide the necessary signal to noise required for these low nitrogen concentrations. In addition to comparing the concentrations and spatial resolution of the nitrogen in the gate oxide, repeatability studies were also performed for each technique.

10:20am **AS-TuM7 Characterization of the Diffusion Properties of Metallic Elements Implanted into Silicon by SIMS**, ***H. Francois-Saint-Cyr,*** *E. Anoshkina,* University of Central Florida; *F.A. Stevie,* Cirent Semiconductor/Lucent Technologies; *L. Chow, K. Richardson, D. Zhou,* University of Central Florida

Metallic elements introduced during device processing degradation or failure of semiconductor devices. Therefore, a better understanding of diffuison phenomena of metallic elements in silicon is useful for quality control and failure analysis. However, the diffusion data of many elements implanted into silicon are not readily available. Because of high sensitivity and excellent depth resolution, secondary ion mass spectrometry (SIMS) is the dominant analytical technique for determining the impurity profiles. When ion implantation, post-heat treatment, and SIMS analysis are combined, the diffusion characteristics of selected metallic elements can be better understood. A systematic investigation of the diffusion of Mg, Cl, K, Ge, Mo, Ca, Ti, V, Cr, and Mn has been carried out employing SIMS. These elements have been initially implanted into silicon wafers as low dose impurities, and then post-heat treatments of the ion-implanted samples have been conducted at different temperatures for a specific time. Following the post-annealing treatments, the depth-profiles of those elements have been obtained by the SIMS analyses. A wide range of diffusion behaviors has been observed for these elements. There possible, quantification of the diffusion process has been achieved based on the differences of the depth-profiles. Furthermore, the diffusion phenomena of different elements are discussed in terms of the activation energy, electronic structures and radii of ions, and their diffusion coefficients.

10:40am **AS-TuM8 Focused Ion Beam Micromachining of Thin Film Copper***, **J. Phillips**, D. Griffis, P.E. Russell,* North Carolina State University

The focused ion beam (FIB) sputtering behavior of thin film copper has been investigated as a function of tilt and rotation of the sample with respect to the incident ion beam. Thin film and single crystal copper was used for this study. The thin film samples were deposited by vapor deposition and shown by x-ray diffraction to be textured . A significant sputter rate increase was observed when milling textured copper at 12 degrees tilt, regardless of sample rotation. In an effort to understand the origin of this sputter rate enhancement, the orientation dependence of single crystal copper (111) was examined. Rotating the sample about [111] with various tilt increments (0-28 degrees in 4 degree steps) demonstrated that channeling effects were responsible for the increased sputter rate, as has been observed.@footnote 1@ In an effort to correlate the single crystal results with the thin film observations, (111) single crystal data was averaged over all rotations to give an overall material removal rate for each sample tilt. Data averaged in this manner directly correlates, within experimental error, with the thin film data suggesting that the crystallinity of the thin film copper is responsible for the observed sputter rate variation. Thus the FIB material removal rate of copper films can be increased by up to 30% by tilting the sample 12 degrees with respect to the ion beam axis. @FootnoteText@ @footnote 1@R. Behrisch, Sputtering by Particle Bombardment I, Springer-Verlag, New York, 1981, pp. 260, 300, 301.

11:00am **AS-TuM9 Surface Analysis and Depth Profiles of Self-healing Copper Aluminum Alloys****, **J.F. Moore**, W.S. Calaway, I.V. Veryovkin, M.J. Pellin,* Argonne National Laboratory

An investigation of the self-protecting properties of Cu@sub 3+x@Al@sub 1-x@ with ternary components (including small amounts of Ag, Ni, Mg, and Mn) is presented. When these alloys are heat treated, a self-terminated (micron-scale) layer rich in alumina is typically formed. The surface film, in principle, can protect the bulk alloy from chemical attack, for example in a molten salt, while maintaining desirable properties of conductivity and thermal stability. In this way the bulk and surface properties of the alloy may be separately optimized. Further, under these circumstances the film can regenerate if dissolved or damaged by rapid diffusion and oxidation of aluminum at the surface. To understand the properties of the initial thermal oxide, we have undertaken surface and depth profiling studies of these alloys using Auger and x-ray photoelectron spectroscopy and secondary neutral mass spectrometry. Results show a strong dependence of the surface composition with heat treatment temperature, alloy composition and oxygen environment. Depth profiling indicates a mixed, aluminum-rich oxide with long diffusion lengths for components in the bulk metal. @FootnoteText@ *Work supported by the U.S. Department of Energy, BES-Materials Sciences, under Contract W-31-109-ENG-38.

11:20am **AS-TuM10 Quasi Atomistic Depth Resolution with Auger Depth Profiling for Oxide / Metal Structure***, **M. Menyhard**, A. Barna, Zs. Benedek, A. Sulyok,* Research Institute for Technical Physics and Materials Science, Hungary

By applying specimen rotation, and grazing angle of incidence for depth profiling, the depth resolution is limited by atomic mixing. To achieve depth resolution of less than 1 nm we have two possibilities; either to decrease the ion energy or to find evaluation routine to correct the effect of atomic mixing. Using very low ion energy, however, the sputtering rate is small resulting in practical problems e.g. extreme cleanliness long measuring time is necessary. Thus it is of great importance to develope evaluation routines for the correction of atomic mixing. We have shown that our trial-and-error routine based on dynamic TRIM simulation can be successfully applied@footnote 1,2@ for the evaluation of the depth profiles where the layers are made of elements with no affinity for compound formation. In this contribution we will report on the extension of our evaluation method for the case of oxide / metal structure. Well characterized silicon oxide /silicon, and oxynitride / silicon structures (specimens were kindly provided by E. Garfunkel of U. Rutgers) with various thickness were depth profiled applying various sputtering conditions. At 0.4 keV Ar sputtering (where the measurement time is reasonable) the depth resolution was found to be around 0.7 nm, while at 0.2 keV better than 0.4 nm. At this later energy, however, practical studies cannot be performed because of the long measuring time. Our evaluation routine was parametrized to reproduce the experimentally measured depth profiles for a given sputtering condition. It turned out that using the same parameters the simulated and measured depth profiles agreed well for the various sputtering conditions. In this way we can apply the higher ion energy (0.4 keV) for routine analysis and using the evaluation routine depth resolution about 0.4 nm could be obtained. @FootnoteText@ @footnote 1@M. Menyhard, Surf. Interface Anal. 26 1001 (1998). @footnote 2@M. Menyhard and A. Sulyok, J. Vac. Sci.Tech A16 1091 (1998).

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