Monday Morning, October 2, 2000

Material Characterization
Room 207 - Session MC-MoM

Depth Profiling

Moderator: F.A. Stevie, Lucent Technologies

8:20am **MC-MoM1 Valence Model Based Correction of Ultra Shallow Depth Profiles***, **O. Brox,*** University of Muenster, Germany*; D. Gehre, E. Zschech,* AMD Saxony Manufacturing GmbH, Germany*; A. Benninghoven,* University of Muenster, Germany

In recent years lateral and in-depth dimensions of microelectronic devices have shrunk by orders of magnitude. The reduction in depth scale was supported by the application of ultra low implantation energies of dopant materials. As a consequence a significant part of the implanted species is located in the uppermost monolayers. The entire thickness of the shallow implants used nowadays of less than 10 nm implanted in oxides with a thickness up to 3 nm complicates the establishment of quantitative SIMS depth profiles. Changing conditions regarding the oxidation state require corrections of the concentration- and depth scale. Distortions can occur also due to the very high peak concentrations (distinctly higher than 1%) resulting from the ultra low implantation energies and from contamination layers as hydrocarbons e.g. For all experiments we used TOF instruments, equipped with flexible gas ion sources and cesium sources (0.6 - 10 keV) for crater formation. Additional gas ion sources (Ar@super +@, 11 keV) have been applied for the analysis of the crater bottom. We have investigated the possibility to compensate the falsification caused by changes of the secondary ion yield in the transient region by applying a suitable correction procedure based on the so-called lattice valency model.@footnote 1@ The success of this correction will be demonstrated by a quantitative depth profile of a 10 keV As-implant into a 3 nm screening oxide. The sputter behavior of undefined organic contaminations as well as of well defined polymer overlayers has been investigated. Sputter yields, damage cross sections, and thermal desorption behaviors will be reported. They allow an estimation of possible depth scale distortions. . @FootnoteText@ @footnote 1@ C. Plog, L. Wiedmann, A. Benninghoven, Surf. Sci. 67 (1977) 565.

8:40am **MC-MoM2 Analysis of Ultra-thin Oxynitride Layers by TOF-SIMS***, **E. Niehuis**, T. Grehl, R. Möllers,* ION-TOF GmbH, Germany*; O. Brox,* University of Münster, Germany

The analysis of very thin oxynitride layers with a thickness below 3 nm becomes increasingly important. Methods are needed to determine the layer thickness, the nitrogen content and the nitrogen distribution in a quantitative manner. The film thickness can be measured with high reproducibility by Ellipsometry, but the SiO@sub 2@/Si interface properties and contamination layers can influence the accuracy. The total N content for very thin films can be quantified using XPS. However, no analytical technique can give the quantitative N distribution with sufficiently high depth resolution and sensitivity. SIMS depth profiling using Cs primary ions in the energy range of 500-1000 eV has been used extensively to study oxynitrides. However, the transient width in this energy range is still above 3 nm. In order to reduce it below the thickness of the film, very low energies of 100-300 eV and/or high impact angles are required. The low sputter yield in this energy regime leads to extremely high Cs surface concentration and to significant sputter rate changes in the transient regime. We have investigated the capabilities of Cs depth profiling at very low energies using TOF-SIMS depth profiling in the dual beam mode. A Cs beam with an energy below 300 eV has been used for the erosion while the center of the sputter crater is analysed with a high energy Ga beam. We have used a new Cs-Xe co-sputtering method to control the Cs surface concentration and keep it in the optimum range for the formation of MCs@super +@ cluster ions. The achievable depth resolution, the sensitivity for nitrogen and the accuracy of the thickness measurement will be discussed in detail.

9:00am **MC-MoM3 Ion Beam Studies of Ultrathin Metal Oxide Dielectrics***, **E. Garfunkel**, B. Busch, H. Schulte, T. Gustafsson,* Rutgers University**INVITED**

There is a strong need to find silicon-compatible high dielectric constant (high-K) replacements for silicon dioxide in microelectronics. This presentation describes recent results on the structure, composition, growth and annealing behavior of high-K combinations of Zr, Hf, Y, and La oxide films. Results will be presented from ion scattering, scanning probe microscopy, photoelectron spectroscopy, electron microscopy and several other surface and thin film methods. It is found that only by cross-correlating several different methods can a definitive analysis of structure and composition (including the depth profile) be given. The interaction of isotopically labeled oxygen with ultrathin oxides at elevated temperatures shows oxygen exchange and diffusion in the films, as well as deleterious silicon dioxide interface growth (that unfortunately accompanies many post-growth anneals). Problems associated with crystallization, interdiffusion, electrical breakdown, and interface structure will also be addressed.

9:40am **MC-MoM5 Matching the High Dose Ultra Shallow As Doping Profiles Measured by X-ray Photoelectron Spectroscopy, Magnetic Sector Secondary Ion Mass Spectrometry and Low Energy Quadrupole Secondary Ion Mass Spectrometry***, J. Zhao, C.M. Jones,* ***T. Neil,*** Advanced Micro Devices*; D. Zhou,* University of Central Florida

SIMS has proven to be a powerful technique for dopant depth profile analysis, however, quantification of dopant concentrations in the outermost several nanometers is still not at all trivial. A major problem arises because SIMS analysis exhibits a surface transient before reaching equilibrium in the sputtering process. Ion yields and sputtering-rate vary significantly during the transient zone and after reaching the equilibrium. The surface transient can be reduced to a few nanometers if a low-energy primary ion beam is used, but a further reduction is hindered by the presence of native oxide of varying thickness on Si wafers. For ultra-shallow As doping profiles using Cs@super +@ primary ions, which increases the negative secondary ion yields, surface oxide significantly depress the As@super ?@ negative ion yield. In the present work, an attempt of using XPS depth profiling to determine the high dose ultra-shallow As dopant profile, with particular interests in the dopant distribution and concentration within the surface transient region, was reported. XPS quantification is free from the ion yield and erosion rate variations of SIMS quantification, and a detection limit of 3e19at/cm@super 3@ for As is demonstrated. XPS results show higher As concentration up to ten times at the sample surface region (<10nm) than that of magnetic sector SIMS result. In addition, the feature of As piled up at the interface of surface oxide and Si substrate was clearly detected in the XPS depth profile, but missed in the magnetic sector SIMS depth profile. After the first 10nm, XPS and magnetic sector SIMS depth profiles match each other, and magnetic sector SIMS demonstrates a superior detection limit down to 5e16at/cm@super 3@. A comparison of the As dopant profiles measured by low energy quadrupole SIMS and magnetic sector SIMS, which was corrected by XPS for the surface transient region, will be further discussed in the paper.

10:00am **MC-MoM6 XPS Characterization of NO Oxynitride Films using Chemical Profiling***, **I.S. Choi**, H.J. Kim, S.Y. Lee,* Hyundai Electronics Industries Co., Ltd., Korea

For the fabrication of MOS devices, the incorporation of nitrogen into thin SiO2 dielectric films has been shown to improve the electrical and structural property of the films. Some benefits of these oxynitrides are as following: (a) resistance to boron diffusion, (b) immunity to hot carrier effects, (c) higher charge-to-breakdown voltage, and (d) reduced charge trapping. These improvements are owing to accumulation of nitrogen atoms at the dielectric/silicon interface. The depth profile and chemical environment of nitrogen in oxynitride films is a critical information to the process control so that a lot of technique to study this material have long been used.@footnote 1,2,3@ However, Ar ion sputtering usually used to acquire depth profile may affect the actual concentration and the bond characteristic of N. In this X-ray photoelectron spectroscopic study of oxynitride films, we adopted successive delicate etching of the films with dilute HF solution as a technique for profiling. It was believed that this kind of chemical profiling would not affect the actual concentration and chemical environment of the films. The etch step was finely controlled to have etch rate of ~0.5 ¢®?/sec and the thickness of every slicely etched films were measured by XPS. With the help of this chemical profiling technique, we observed, for the first time, the selectivity of the etch rate between the thermal oxide and oxynitride films. Much difference between the etch rate of two films was used to remove upper oxide layer and study remained pure oxynitride film. Therefore we could directly observe the thickness of NO oxynitride interlayer to be about 6¢®?.@footnote 4@ We also have studied the bond structure, thickness, and composition of the oxynitride layers by deconvoluting Si2p and N1s XPS spectra. The results of the study on the composition and the chemical environment of the oxynitride films will be discussed in this presentation. @FootnoteText@ @footnote 1@ Rama I.Hegde, Philip J. Tobin, Kimberly G. Reid, Bikas Maiti, and Sergio A. Ajuria, Appl. Phys. Lett. 66(21), 2882 (1995) @footnote 2@ E. P. Gusev, H. C. Lu, T. Gustafsson, E. Garfunkel, M. L. Green, and D.Brasen, J.

Appl. Phys. 82(2), 896 (1997) @footnote 3@ M. R. Frost, C. W. Magee. Appl. Surf. Sci. 104/105, 379 (1996) @footnote 4@ E. A. Irene, Q. Liu, W. M. Paulson, P. J. Tobin, and R. I. Hegde, J. Vac. Sci. Technol., B14, 1697 (1996)

10:20am **MC-MoM7 The Effect of Ion Acceleration Voltage on Interface Resolution During Depth Profiling and the Application of Advanced Data Analysis Techniques***, **S.J. Hutton,*** Kratos Analytical, UK*; N. Fairley,* CASAXPS Ltd, UK*; D. Surman,* Kratos Analytical, UK

The effect of ion acceleration voltage on interface resolution during destructive depth profiling of a challenging multilayer sample was investigated. A compact, high speed, Kaufman ion source combined with X-ray photoelectron spectroscopy (XPS) enabled efficient concentration depth profiling through several hundred nanometer thick layers. The Kaufman source exhibits extremely high sputter rates at low ion beam acceleration potentials reducing ion induced mixing of the surface atoms. Atomic concentration profiles through inorganic oxide layers were recorded as a function of ion acceleration voltage. The improvement in interface resolution with decreasing acceleration voltage was clearly demonstrated. Chemical state information was retained with some reduction of the oxide layer observed due to preferential sputtering of oxygen from the surface during profiling. A detailed examination of the O 1s envelopes was also performed using principal component analysis (PCA) and non-linear least-square curve fitting (NLLSCF). It was shown that while four abstract factors characterised the O 1s data only two were of chemical significance with the remaining pair describing trends associated with the measurement process. Sub-sampling the periodic nature of the data matrix allowed underlaying line-shapes to be identified which were used to support the NLLSCF data reduction.

10:40am **MC-MoM8 Quantitative Comparison between AES and SIMS Depth Profiles of a Double Layer Structure of AlAs in GaAs Using the MRI-model***, **S. Hofmann,*** Max-Planck-Institute for Metals Research, Germany*; A. Rar,* University of Alabama*; D.W. Moon,* Korea Research Institute of Standards and Science, Korea*; K. Yoshihara,* National Research Institute for Metals, Japan

Application of the so called mxing-roughness-information depth (MRI)-model@footnote 1@ to the quantitative reconstruction of the in-depth distribution of composition, is demonstrated by a comparison of SIMS and AES depth profiles. A GaAs/AlAs reference sample consisting of two layers of AlAs (1 ML and 36 ML) separated by 44 ML of a GaAs matrix was depth profiled using almost identical sputtering conditions: Ar+ ions of 3 keV impact energy and 52 (SIMS: CAMECA 4f) and 58 deg. (AES: VG Microlab 310F) incidence angles. Both the Al+ intensity of the SIMS profile and the Al (LVV) intensity of the AES profile were quantified by fitting the measured profiles with those calculated with the MRI model, resulting in the same mixing length of 3.0 nm ± 0.3 nm, similar roughness parameter (1.4-2 nm), and negligibly small information depth (0.4 nm)for SIMS. Whereas practically no matrix effect was observed for Al+ in the SIMS profile, quantification using dimer ions (Al2+) shows a marked nonlinearity between concentration and intensity.@footnote 2@ @FootnoteText@@footnote 1@S. Hofmann, Surf. Interface Anal. 27,(1999)825. @footnote 2@A. Rar, D.W. Moon and S. Hofmann, J. Surf. Anal. 6,(1999)29.

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