Manufacturing Science and Technology
Room: C-109 - Session MS+SE-MoM

In-Situ Monitoring and Metrology for Coating Growth and Manufacturing
Moderator: A. Diebold, International Sematech

8:20am **MS+SE-MoM1 Product Development and Yield Enhancement through Failure Analysis of Integrated Circuits with Scanning Capacitance Microscopy**, ***P. Tangyunyong***, *C.Y. Nakakura*, Sandia National Laboratories

Scanning capacitance microscopy (SCM) has become a widely used metrology tool in the microelectronics industry due to its ability to measure two-dimensional free carrier profiles with nanometer-scale resolution. To date, SCM has been used primarily to characterize source/drain formation by imaging cross-sectioned, metal-oxide-semiconductor field effect transistors (MOSFETs). We have extended the role of SCM in our Fab from an off-line research instrument to a routinely-used failure analysis tool, active in providing feedback in new product development, process validation, and yield enhancement. The SCM measurement can be performed on any two-dimensions of the sample, thus providing unique information that cannot be obtained with other analysis techniques. This information has been instrumental in helping to identify several yield-limiting defects in our CMOS device product line. In addition, SCM measurements are performed in-house with quick turnaround, yielding a considerable advantage over off-site analysis techniques, such as secondary ion mass spectroscopy. The methodology for performing both top-down (parallel to the wafer surface) and cross-sectional SCM measurements will be presented. We will show, in detail, several examples of how SCM information has been used to identify the root causes of device failures and discuss some of the corrective actions taken to reduce defects and improve yield.

This work was performed at and supported by Sandia National Laboratories under DOE contract DE-AC04-94AL85000. Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation for the United States Department of Energy.

8:40am **MS+SE-MoM2 Integrated CD Metrology for Poly Si Etching**, ***G.P. Kota***, *C. Lee*, Lam Research Corporation, *T. Dziura, A. Levy*, KLA-Tencor Corporation

Advanced process control (APC) is gaining widespread use because of the costs associated with 300mm wafer processing and because of the stringent control required for CD and profile due to the shrinkage of critical feature dimension. APC can be used in Feed forward, Feed back and Fault detection control modes. The KT metrology module called iSpectra is integrated on to the Lam 2300 Versys etch platform. This modular design allows for real time APC. Integrated metrology also enhances the overall equipment efficiency. A comparison of iSpectra, CD-SEM, and x-SEM results will be presented. iSpectra shows good correlation to the CDSEM measurements as well as x-SEM profiles. In addition, iSpectra repeatability is superior to conventional methods such as CD-SEM. It is common knowledge that 193nm PR shrinks during CDSEM measurements due to exposure of the PR to e-beam. This shrinkage has been measured to be up to 17nm after about 30 repeated measurements on the CDSEM. In comparison, the iSpectra measurement technique results in minimal CD shrinkage.

9:00am **MS+SE-MoM3 Metrology for Manufacturing**, ***U. Whitney***, KLA-Tencor **INVITED**

9:40am **MS+SE-MoM5 Measurements of Shallow Trench Isolation by Normal Incidence Optical Critical Dimension Technique**, ***J. Hu***, *D. Shivaprasad, F. Yang, R. Korlahalli*, Nanometrics, Inc.

Shallow Trench Isolation (STI) has emerged as one of the primary techniques for device isolation in complementary metal-oxide semiconductor (CMOS) technologies. This device isolation technology has become extremely important to satisfy the high density requirements of modern integrated circuits, It is of paramount importance to measure the critical dimensions of the STI structure. Currently used CD-SEMs cannot identify the rounding typically present at the bottom or top of the profile, and it is difficult to differentiate between the top and bottom line-width values. X-SEMs which can give the profile information require the destruction of the wafer. In this paper we present the work done on STI using the Optical Critical Dimension (OCD) technique. This technique measures line or trench profiles using Normal Incidence Polarized Reflectometry with a sensitivity to sub-50nm grating lines. In the OCD technique, a broadband polarized light beam is focused onto the grating surface, and the reflected 0th order is measured as a function of wavelength. The data obtained by measuring the grating structure gives a signature of the profile structure which is analyzed in real time using Rigorous Coupled Wave Analysis (RCWA). Since the data is fitted in real time, there is no requirement for library generation, which makes the analysis simpler and easier to extend to other structures without the need of lengthy re-generation of a new library of profile data. Data from STI wafers before and after ashing (removal of the developed resist) will be presented. Sensitivity to the oxide notching and repeatability data will also be presented.

10:00am **MS+SE-MoM6 The Evolution of Single Atomic Steps on vicinal Si(111) in NH_4F**, ***J. Fu***, National Institute of Standards and Technology, *H. Zhou,* University of Maryland, *J.A. Kramar, R. Silver*, National Institute of Standards and Technology

Determining the width of a feature or the scale in a pitch measurement with appropriate accuracy is fundamental for process control in state-of-the-art semiconductor manufacturing. To meet these needs as well as the future measurement and calibration needs of the emerging nanomanufacturing industry, the National Institute of Standards and Technology (NIST) has been pursuing research and development on techniques for the fabrication and measurement of atom-based dimensional standards. The key elements in the development of atom-based standards are the ability to prepare atomically ordered surfaces,and the ability to count the atoms making up the features of interest. One of the most difficult challenges in atom-based metrology has been the fabrication of an appropriate atomic template. Atomically ordered surfaces provide an intrinsic template which have both scale and orthogonality. Using Scanning Probe Microscopy(SPM), We have examined the surface produced by etching several different vicinal Si(111) sample in 40% NH_4F. In agreement with others, we find that deoxygenation of the etchant generally reduces the number of triangular etch pits. The formation of single atomic steps is evolved from these etch pits. These etch pits undergo nucleation, growth, merging, and corner rounding which can lead to single atomic steps. We also find that for maximum uniformity and minimum root mean square roughness, a certain minimum miscut angle is required. This angle is related to the maximum clear terrace width, which in turn is related to the relative etching rate of the step-edge sites and the terrace sites. The time evolution of the surface-smoothing etching process was also examined.

10:20am **MS+SE-MoM7 Real Time in situ Spectroellipsometry**, ***J.A. Woollam***, *B. Johs*, *J. Hale*, J. A. Woollam Co., Inc. **INVITED**

This talk reviews applications of spectroscopic ellipsometry for in situ monitoring and control during deposition, themal processing, and etching of surfaces and thin-films. In situ spectroscopic ellipsometry is valuable for calibrating film growth and etch rates, controlling the thickness of each layer in multi-layer structures, and investigating nucleation phenomenon. It is also useful for measuring surface and interfacial roughness, substrate and film optical constants (with and without surface oxides), alloy composition, and substrate temperature. There have been numerous challenges to implementing in situ spectroscopic ellipsometry, including how to deal with substrate wobble and the effects of windows, and how to accurately measure thickness and material properties during growth of large numbers of layers in multi-layer stacks. Solutions to these practical problems will be discussed, and example applications described.

11:00am **MS+SE-MoM9 Real Time Process Control by Spectroellipsometry**, ***D. Daineka***, *P. Bulkin, T. Novikova, B. Drévillon*, CNRS, Ecole Polytechnique, France

In situ ellipsometry is well known to be the most sensitive, non-invasive tool for monitoring and control of thin film growth. In the fabrication of optical coatings and thin films in general the refractive index of the material is usually assumed to remain constant within a single layer. With such assumption only optical thickness of the layer can be controlled. For modern complex structures, however, even insignificant variation in the refractive index can be very detrimental to the final performance of the coating. Simultaneous real-time determination of refractive index and growth rate is required in order to comply with strict specifications. If the index departs from the pre-calculated target value, one has to adjust process parameters. In PECVD such control variables are gas flows of the precursors. We report on the closed-loop control of the silicon oxynitrides deposition by in situ phase modulated kinetic spectroellipsometry using a direct numerical inversion algorithm for the real-time reconstruction of refractive index and layer thickness. This technique is tested on constant index layers as well as on graded refractive index profiles and shown to be efficient and reliable.

11:20am **MS+SE-MoM10 In-Situ Studies of the Amorphous to Microcrystalline Transition of Hot-Wire CVD Si:H Films Using Real-Time Spectroscopic Ellipsometry**, ***D.H. Levi***, *B.P. Nelson*, *J.D. Perkins*, National Renewable Energy Laboratory

In-situ real-time spectroscopic ellipsometry (RTSE) provides detailed information on the evolution of the structural and optical properties of Si:H films during growth.[1] We have used in-situ RTSE to characterize the morphology and crystallinity of hot-wire CVD (HWCVD) Si:H films as a function of substrate temperature T_s, hydrogen dilution $R=[H]/[H+SiH_4]$, and film thickness d_b. Transitions from one mode of film growth to another are indicated by abrupt changes in the magnitude of the surface roughness during film growth. The degree of crystallinity of the film can be determined from the bulk dielectric function. We have studied the growth parameter space consisting of R from 0 to 14, T_s from 250°C to 550°C, and d_b from 0 to 1 µm. For each set of R and T_s values, the structural evolution of the film can be characterized by the shape of the surface roughness thickness d_s versus bulk thickness d_b curve. In contrast to studies done by Collins et al on PECVD growth of Si:H films, our studies of HWCVD growth find no conditions where d_s remains constant after coalescence of the initial nucleation centers. Most of the films grown within the range of parameters studied exhibit a secondary nucleation and coalescence signature. The transition between a-Si:H and uc-Si:H growth is near the R=3 to R=4 dividing line. Initial coalescence of purely uc-Si:H material does not occur until R>8. We have verified the RTSE crystallinity classification using ex-situ Raman scattering.

[1] R.W. Collins, Joohyun Koh, H. Fujiwara, P.I. Rovira, A.S. Ferlauto, J.A. Zapien, C.R. Wronski, R. Messier, Appl. Surf. Sci., 154-155, 217-228 (2000).

11:40am **MS+SE-MoM11 Post-Deposition Control of Resistivity and Anisotropy in ZnO Thin Films**, ***J.S. Lewis***, *B. Stoner*, *C. Pace*, MCNC

A method for post-deposition control of the resistivity of ZnO thin films has been developed, and a method for providing anisotropic sheet resistance in the plane of the film has been demonstrated. Military needs for real-time image processing can be met using thin film analog image processor (TAIP) devices. TAIP chips provide compact and power-efficient analog processing, including high- or low-pass spatial frequency filtering. The analog spatial filters are based on the RC time constant of the circuit, and therefore require thin films with controlled, repeatable sheet resistance in the range of MΩ/sq. This range of sheet resistance can be difficult to achieve with good repeatability for inorganic films. ZnO thin films were sputtered from an undoped ZnO target by RF magnetron sputtering. The as-deposited sheet resistance of the films was in the range 5-50 kΩ/sq. Post deposition processing yielded films with sheet resistance in the range from the as deposited value to > 100 MΩ/sq. Target values of sheet resistance were obtained routinely. Using an in-situ monitor of sheet resistance during processing resulted in much better repeatability than that possible for as-deposited films. For TAIP chips, anisotropic sheet resistance in the plane of the film can allow more sophisticated algorithms for image processing. Post processing techniques were used to fabricate ZnO thin films with sheet resistance anisotropy ratios in the range of 2:1 to 25:1, and larger anisotropies should be possible. This work was sponsored by DARPA (contract no. DAAD19-00-1-0002).

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