Thursday Morning, October 18, 2007

Manufacturing Science and Technology

Room: 615 - Session MS-ThM

Metrology and Characterization for Manufacturing

Moderator: J. Randall, Zyvex Corporation

8:00am **MS-ThM1 Measurement of GST Thin Film Composition and Thickness**, ***M. Ye***, *C.C. Wang, G. Conti,* Applied Materials, Inc.

Recent studies demonstrated that phase change memory (PCM) can achieve fast switching speed, good reversibility and scalability, making it the most promising alternative non-volatile memory (NVM) technology for the next decade. Currently PCM is being actively studied in semiconductor industry, with $Ge_2Sb_2Te_5$ (GST) being the most widely investigated material. GST film thickness and composition are two important quantities that require close monitoring in manufacturing. We have experimented with a number of measurement techniques including x-ray reflectivity (XRR), ellipsometry, wavelength dispersive x-ray fluorescence (WDXRF), energy dispersive x-ray fluorescence (EDXRF), energy dispersive spectroscopy (EDS), Rutherford backscattering spectrometry (RBS), x-ray photoelectron spectroscopy (XPS), inductively coupled plasma optical emission spectroscopy (ICP-OES), and low energy x-ray emission spectroscopy (LEXES). The advantages and limitations of the various characterization and metrology techniques for GST film composition and thickness measurement are compared. XRR can measure GST film physical thickness and density independently with good precision. Our study of WDXRF shows that there is little interference between antimony and tellurium peaks, and that GST film thickness and composition can be measured simultaneously with good precision. XRR and WDXRF can often provide complementary information, which can be very helpful for troubleshooting process and hardware issues. More details will be presented in the paper. In EDXRF and EDS measurements, antimony and tellurium peaks overlap, and good peak modeling is required to deconvolute the peaks to ensure accurate measurement. RBS in general is a very good standardless analytical technique. However its use for GST application is limited since it can not resolve antimony and tellurium peaks. Particle-induced x-ray emission (PIXE) can be used together with RBS at the cost of measurement accuracy, yet PIXE still requires peak profile modeling. ICP-OES provides reasonable accurate results, but it is a destructive technique and thus not practical for process monitoring. We have also looked into XPS and LEXES for GST-related applications. The effects of sputtering process parameters such as pressure, temperature and wafer bias on GST film composition are discussed. The GST film composition variation through a sputtering target life is also monitored.

8:20am **MS-ThM2 Gate Oxide Process Control Optimization by XPS in a Semiconductor Fabrication Line**, ***A. Le Gouil***, *N. Cabuil, P. Dupeyrat,* STMicroelectronics, France, *B. Dickson, M. Kwan,* Revera, *D. Barge,* NXP, *O. Doclot,* STMicroelectronics, France, *J.C. Royer*, CEA/LETI-Minatec, France

The introduction of thinner films such as 15-20 Å SiON gate oxides makes in-line metrology challenges more complex. Nitrogen dose in the SiON film is strongly process deposition dependent and is one key parameter of advanced CMOS technologies. Therefore, optimized process control has to be implemented in-line to ensure process stability. Measurement techniques such as X-Ray Metrology have to move from offline characterization laboratories to fabrication lines and ultimately to in-line metrology. Among these techniques, X-ray Photoelectron Spectroscopy (XPS) is one of the best adapted metrology methods to ensure nitrogen dose monitoring of SiON gate oxides. Until recently, decoupled plasma nitridation (DPN) process monitoring has been performed on monitor wafers. However, measurements performed on monitor wafers may not fully represent actual electrical properties at the device level. Measurements on production lots allow inline detection of process excursions and provide real time feedback of process chambers' stability. Additional productivity improvements are reducing consumption of monitor wafers and their processing as well as data acquisition for correlations with device reliability parameters. The implementation in production of SiON gate monitoring on production lots implies to fully characterize the nitridation process on patterned wafers. This study is dedicated to a comparison between monitor and patterned wafers of DPN processes for 65nm node technology and below. Measurements are carried out in a next generation XPS tool with a 35µm spot size and pattern recognition capability that enable material metrology on product wafers. XPS measurements on patterned wafers are performed in specific test structures which dimensions are 50µm x 70µm using an Al Ka monochromatic X-ray source. A larger X-ray spot providing higher signal level is available for measurements on monitor wafers. First, gate oxides will be characterized for each process and tool measurement precisions will be shown. Second, nitrogen dose and thickness uniformity over the wafer will be compared and discussed. Third, different mappings protocols will be studied to identify the best compromise between throughput and an optimized mapping representative of process distribution. Finally, we will conclude with a selection of an optimized process control strategy of gate oxides.

8:40am **MS-ThM3 The Helium Ion Microscope and Applications for Semiconductor Manufacturing and Characterization**, ***J. Notte***, *N.P. Economou, B. Ward, R. Hill,* ALIS Corporation (Carl Zeiss SMT)**INVITED**

ALIS Corporation (a Carl Zeiss SMT company) has developed a helium ion microscope which provides high resolution images with strong contrast mechanisms. Although technically a focused ion beam (FIB) the microscope operates more like a scanning electron microscope (SEM) but with higher resolution and stronger contrast. The technology and its general capabilities are being presented in another session. This paper addresses some of the semiconductor manufacturing applications which are well suited to the helium ion microscope. Process development and process monitoring require high resolution imaging and contrast mechanisms that are sensitive to material differences. The helium ion microscope is well suited to these tasks. In particular, the secondary electron images can reveal fine details which contain topographic or material information. Grain formation is evident through well established channeling contrast mechanisms. Electrical properties can be revealed by virtue of the beam induced voltage contrast effects. Images can also be generated from the scattered helium ions, providing the ability to distinguish different materials based on their atomic number. This also has the advantage of giving a resolution which is superior to the presently used EDX analysis. Testing has been conducted to look for any effects of damage to semiconductor devices. In particular, a series of tests were conducted to examine any possible effect on the transistor turn on voltages, Vt, after various exposures to helium ions. Test results show no measurable shift. Higher dosages have been tested to look for other signs of damage. Additional manufacturing applications will be presented.

9:20am **MS-ThM5 Characterization of Electronic Materials with Atom Probe Tomography**, ***T. Kelly***, Imago Scientific Instruments **INVITED**

Atom probe tomography provides three-dimensional structural and compositional analysis of materials at the atomic scale. It has been applied increasing frequently in the past few years to materials characterization challenges in the semiconductor industry. Specimen preparation advances have made it routine now to extract and analyze materials from wafers and even finished components. Major developments in LEAP technology by Imago Scientific Instruments have led to greater facility for running specimens and greater detail in quantitative analysis. Important examples of analyses of CMOS semiconductor structures and devices, thin-film multilayer structures, and even organic nanostructures will be shown.

10:00am **MS-ThM7 Structural Fingerprinting of Nanocrystals on the Basis of High Resolution Transmission Electron Microscopy and Open-Access Databases**, ***P. Moeck***, Portland State University, *P. Fraundorf*, University of Missouri at St. Louis

It is well known that many nanocrystals can not be identified from their powder X-ray diffraction pattern as it is customary for micrometer sized crystals. When nanocrystals are involved, i.e. the kinematic scattering approximation is sufficiently well satisfied for fast electrons; a new strategy for lattice-fringe fingerprinting from Fourier transforms of high-resolution phase contrast transmission electron microscopy (HRTEM) images is feasible. This strategy relies on crystal structure information that is transferred to HRTEM images in the weak-phase object approximation. Such information is contained in (i) the projected reciprocal lattice geometry, (ii) the phase angle distribution (in the imaginary part of the Fourier transform of HRTEM images), and (iii) the relative intensities at the positions of reciprocal lattice points. Systematic intensities close to zero at certain lattice points may suggest kinematical absences of diffracted beams, aiding the structural fingerprinting. Nanocrystal structure specific limitations to the application of this strategy are discussed. The first tests of this strategy have been promising and the whole procedure could be automated in the current generation of computer controlled HRTEMs. When automated, mixtures of nanocrystals could be analyzed both qualitatively and quantitatively. Since each nanocrystal would be identified individually and thousands of nanocrystals could be processed automatically, the detection limits of lattice fringe fingerprinting could readily be pushed to levels that are by far superior to those of traditional powder X-ray diffraction fingerprinting. The Crystallography Open Database (COD, http://crystallography.net) and its mainly inorganic subset (http://nanocrystallography.research.pdx.edu/CIF-searchable/cod.php) are discussed because the whole lattice-fringe fingerprinting concept is only viable if there are comprehensive databases to support the identification of unknown nanocrystals. While the COD contains the atomic coordinates, space group, lattice parameters, and other crystallographic information for more than 50,000 compounds, we provide at the research servers of Portland State University in addition interactive 3D structure visualizations and theoretical 2D lattice-fringe fingerprint plots for approximately 10,000 compounds for the mainly inorganic subset of the COD.

10:20am **MS-ThM8 The CD-AFM Technique as a Mean to Accelerate Advanced Process Development for the 45nm Node and Beyond**, ***J. Foucher***, CEA-LETI-MINATEC, France, *E. Pargon*, LTM-CNRS, France, *P. Faurie*, CEA-LETI-MINATEC, France, *M. Martin*, LTM-CNRS, France

As devices dimensions and architectures move towards the 32nm node, CD metrology needs for both production process monitoring and process development must cope with new challenges affected by unknown new materials, architectures and processes. One of the main challenges for advance node requirement is the accuracy in CD metrology which becomes mandatory not only at the R&D level but also at the manufacturing level. By simplicity and also because there was no impact on production yield, the semiconductor industry has traditionally followed a single CD value for use in statistical process control as a representation of their products on a wafer. For advanced processes, the control of profile shape and Line Width Roughness (LWR) is increasingly critical and subsequently the need in metrology accuracy for improvement of sidewall angle (SWA) and LWR is necessary. Through various examples of process development as regards advanced lithography, front-end or back-end etching, we will show that the CD-AFM technique represents a great opportunity to add accuracy in the Semiconductor manufacturing world and will allow other metrology techniques to progress in term of accuracy and subsequently will permit to decrease R&D and manufacturing cost.

10:40am **MS-ThM9 Analysis of Ion Implantation Damage in Silicon Wafers**, ***R.K. Ahrenkiel***, University of Denver

Ion implantation has become the standard method for building high-density, microelectronic devices. Rapid thermal annealing (RTA) is required to activate the implanted donor and acceptor species. Also, RTA is required to heal the lattice damage created by heavy ion implants such as boron, BF2, phosphorous and arsenic. The RTA process is required to maintain the structural integrity of the semiconductor used for submicron-integrated circuits, as dopant diffusion will destroy the implantation pattern using a long-duration heat treatment. There is a trade-off between the maintenance of the implantation pattern and the elimination of radiation damage. A quick, efficient, and contactless diagnostic of the implantation damage is highly desirable in both research and production environments. The resonant-coupled photoconductive decay (RCPCD) technique uses a deeply penetrating, low-microwave-frequency probe in conjunction with pulses from a tunable laser source. The recombination lifetime of the implanted region decreases many orders of magnitude as a result of implantation. The implanted region has electrical transport characteristics that are similar to those of amorphous silicon. For example, the recombination lifetime of the implanted regions becomes sub nanosecond, and similar to that of amorphous silicon. I have found the doubled YAG laser frequency of 532 nm to be especially useful for sensitivity to implantation damage. RTA restores the crystalline structure, and the degree of restoration depends on the RTA process. The implantation damage is manifested in a sharp decrease in the recombination lifetime when using strongly absorbed light, that is primarily absorbed in the implanted region. In addition, the as-implanted layer acts as a "sink" for minority carriers that are generated in the undamaged crystalline regions. The lifetime increases with various annealing processes, and one can correlate the lifetime changes with the specific annealing protocol. I will also show data for the sheet resistance, which is correlated with the increase of lifetime in the implanted volume. In summary, I will present a method for quickly evaluating the damage elimination of various implantation-annealing processes.

Authors Index

Bold page numbers indicate the presenter