Manufacturing Science and Technology
Room: C3 - Session MS-ThA

Manufacturing Issues in Nanoelectronics, PV and SSL
Moderator: C.Y. Sung, IBM Research Center

2:00pm **MS-ThA1 Nanoelectrical and Nanomechanical Interconnect and Device Metrology for CMOS Extension**, ***R.E. Geer***, *C.H. Chong, Y. Wang*, University at Albany **INVITED**

So-called 'equivalent scaling' which is dominating the extension of CMOS from the 'pure' scaling regime places inordinate demands on interconnect performance both for conventional CMOS switch configurations as well as alternate switch materials (III-V, carbon-based). As a result, substantial advances are required in fundamental metrology measurements of thin film electrical continuity in conventional intra-core and core-core interconnects as well as innovative approaches for electrical and mechanical interconnect metrology for alternate CMOS material sets. Here, we present nanoscale electrical continuity profiling of ultra-thin barrier and Cu films for conventional interconnects as well as nanoscale electrical metrology of alternate material (graphene-based) interconnects. For the former, it is shown that sub 2-nm films, although electrical conductive, show local reduction in electrical continuity that correlate to line-edge-roughness in patterned interconnect test structures. In contrast, alternate interconnect materials (e.g. single-layer graphene) are shown to exhibit electrical uniformity although local defectivity and electrostatic doping (for the case of interconnect applications) must be sufficiently controlled for use in conventional CMOS geometries.

2:40pm **MS-ThA3 New Mechanism for Optically Stimulated Point Defect Control In Ultra-Shallow Junction Formation**, *P. Gorai, Y. Kondratenko*, ***E.G. Seebauer***, University of Illinois at Urbana-Champaign

Formation of pn junctions in advanced Si-based transistors employs rapid thermal annealing (RTA) after ion-implantation in order to increase the activation of dopants. There has long been suspicion that the strong lamp illumination in RTA equipment may nonthermally influence the diffusion of dopants. The present work describes the evidence for a photostimulated diffusion mechanism based on electrostatic coupling between interface and Si bulk. Photostimulated effects on diffusion of boron were studied in ion implanted crystalline silicon samples. Low intensity illumination (2 W/cm^2) was used for nonthermal photostimulation during soak annealing using with resistive heating of the substrate. This experimental design allowed decoupling of heating and illumination. The samples were annealed at different temperatures and dopant diffusion and activation data was compared between experiments with and without illumination. Experimental data in conjunction with continuum simulations showed that light interacts with the charged defects at Si-SiO_2 interface and modulates the electrical field arising from near-surface band bending. The effects of this modulation exhibited profound effect on diffusion profile evolution near the surface and in the bulk. Simulations results were further employed to elucidate underlying physical mechanism of this effect.

3:00pm **MS-ThA4 Thickness/Composition Metrology of Ultra-thin Lanthanum Oxide Cap Layer for CMOS Metal Gate Work Function Tuning**, ***C.C. Wang***, *Y. Cao, G. Liu, X. Tang, Y. Uritsky, S. Gandikota*, Applied Materials Inc.

Beyond the 45 nm node CMOS application, metal gate and high-k dielectric are used and many new thin film materials are developed. In order to reduce the threshold voltage of the CMOS gate, the matching of the metal gate work function with the silicon band position is important. For NMOS work function tuning, lanthanum oxide (LaO_x) thin film is used. Device performance demands the use of less than 10 Å thick LaO_x and the stringent control of thickness and composition uniformity (1 to 2% 1σ) on 300 mm wafers. However, metrology of this new material is very difficult. First the LaO_x cap layer is so thin, only ellipsometry, X-ray photoelectron spectroscopy (XPS) and X-ray fluorescence spectroscopy (XRF) have the required sensitivity. Second, the composition of LaO_x changes with air exposure time due to its reaction with ambient moisture; such behavior renders ellipsometey and XPS ineffective, because the composition result and the thickness result from both techniques are strongly correlated in the case of ultra-thin film measurements. This leaves XRF to be the only candidate for both composition and thickness measurements. The main advantage of XRF is that the X-ray signals from the sample are proportional to the surface doses (atoms/cm^3) of the elements in the ultra-thin film; hence, it is simple to calibrate the tool and develop measurement recipes. To satisfy the new metrology needs, wavelength dispersive XRF (WD-XRF) and energy dispersive XRF (ED-XRF) techniques were developed.

For tool calibration and drift monitoring, a LaO_x thin film standard with known thickness, density and composition had to be prepared. Due to high reactivity of LaO_x in air, it was difficult to prepare a stable standard and to determine all its attributes. To overcome this problem, a 200 Å thick LaO_x thin film on silicon standard capped with a thin TiN layer was prepared, its thickness and density were measured by X-ray reflectivity and its composition was derived by the XRF measurement itself by an ingenuity method. Due to the good sensitivity of WD-XRF to both La and O signals, recipe was developed to monitor the composition of freshly deposited PVD LaO_x thin films and their change with ambient exposure time. The results showed that the LaO_x ultra-thin film deposited with lanthanum oxide target was more stable in air than those deposited with a La metal target. ED-XRF recipe was developed to monitor the LaOx thickness uniformity on 300 mm wafers. The main advantage of ED-XRF was its small X-ray spot size that afforded 3 mm edge exclusion measurements. Study showed ED-XRF had < 1% (1σ) precision with good throughput of < 60 seconds per data point.

3:40pm **MS-ThA6 Sidewall Image Transfer for Sub Lithographic Pitch Scaling for the 22nm CMOS Node & Beyond**, ***S. Kanakasabapathy***, IBM Research, *R.H. Kim*, Global Foundries, *A. Ko, A. Metz*, Tokyo Electron Limited, Japan, *T. Osabe*, Hitachi Technologies, Japan, *S. Schmitz, T. Standaert*, IBM Systems and Technology

Critical Dimension (CD) Scaling and Pitch Scaling for the past several decades have sustained the Microelectronics Industry's march along the Moore 's law. Wavelength, Numerical Aperture & Immersion assisted index scaling have made possible such pitch scaling in a fashion relatively transparent to Etch. However with the technical and manufacturing challenges faced by Extreme Ultraviolet (EUV) wavelength scaling, Etch/Integration assisted Pitch Scaling is being explored. Ground rule challenges have grown exponentially since Sidewall Image Transfer (SIT) was proposed as such a technique for pitch halving.

We present herein SIT challenges for obtaining sub 80 nm pitches for Line space levels compatible with Front End of Line applications. Line Edge Roughness (LER) and Line width Roughness (LWR) measurements for these integration schemes will be presented with options to mitigate them.

4:00pm **MS-ThA7 Wafer-level Process Sampling, Metrology and Testing for MEMS and Solar Photovoltaic Applications**, ***V. Ngo***, FEI Company

As MEMS (Micro-Electro-Mechanical Systems) devices further proliferate many industrial and consumer products, the need for fast characterization becomes critical to production process support and time-to-answer in failure analysis. For example, a Dual-Beam can be used to characterize the MEMS fabrication processes by cross-sectioning the area of interest using a focused ion beam and imaging the uncovered feature of interest for metrology and process evaluation using a scanning electron beam or via the ion beam itself. The ion-beam can also be used to weld and cross-section fragile suspended features without additional process steps such as resist backfilling. Most MEMS components, however, are very large on the order of 10s-100s microns, which can lead to long sample preparation times. Furthermore, localized gas chemistry injection on the micron-level at the point of beam-sample interaction further enhance milling rate to support wafer-level multi-site sampling for near-production process support. FA work in MEMS packaging and TSV development for MEMS-CMOS integration also have demonstrated benefits from the gas-enhanced FIB de-processing.

In addition to sample preparation throughput, it is possible to use a micromanipulator probe to remove specific components of the device for characterization. This work also demonstrates that A FIB system configured with such an in-situ sample lift-out probe can remove specific components at their attachment points and lifting them out to characterize their etch profile, rather than attempting to ion mill a large area away to enable access. Both gas-enhanced and lift-out approaches can significantly reduce the amount of time required for a cross-section of the device, and improve the quality of data obtained.

4:20pm **MS-ThA8 Establish Degradation Rates of Photovoltaic Modules and Systems Trough Comprehensive Electrical and Mechanical Analysis**, ***A. Leyte-Vidal***, *K. Davis, W. Wilson, R. Reedy, N. Hickman*, Florida Solar Energy Center, *S. Kurtz*, National Renewable Energy Laboratory

Performance degradation of photovoltaic modules and systems follows a progression that is dependent on multiple factors. Many of the mechanisms responsible for degradation are difficult to simulate in a laboratory setting. While accelerated aging tests are a valuable tool in evaluating photovoltaic components and systems, long-term monitoring of systems installed in the field is the true test of reliability. A comparison of the original and weathered power output of several different photovoltaic technologies dating back to 1998 is presented here, along with an analytical description of the degradation and weathering effects responsible for reduced power production over extended periods of time. Experimental data has been collected on diverse generations of photovoltaic modules installed throughout the state of Florida, where the systems have been subjected to long-term exposure in a hot, humid climate. Some of the module degradation mechanisms may be attributed to optoelectronic effects, while others are more mechanical in nature (e.g. encapsulation and delamination issues). The effect of performance degradation on the system's economics and life-cycle energy costs has been presented in order to better quantify the impact of the different degradation mechanisms. While working to reduce the initial degradation effects is of vital importance and has received considerable interest in the past, a better understanding of the long-term degradation mechanisms inherent in this technology is also fundamental in the effort to improve the reliability of photovoltaic modules and systems.

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