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Advanced Spectroscopic Ellipsometry Application for Multi-layers SiGe at 28nm Node and Beyond

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Spectroscopic Ellipsometry (SE) is a commonly used non-destructive method to perform in-line monitoring of film thicknesses and optical indexes for the semiconductor industry. SE metrology can also monitor film composition by correlating optical indexes to species concentration. Germanium concentration (Ge%) measurement after SiGe epitaxial layer is a critical application at 40/28nm nodes to evaluate strain induced in the PMOS channel; however, for 28nm and beyond, metrology needs to monitor Ge% on more complex SiGe film processes. This paper describes accurate and stable Ge% measurements on multi-SiGe layers by using optimized optical models and multiple correlation methodologies using SE metrology and how SiGe and Si-cap thicknesses can be reported simultaneously and independently. This paper demonstrates how to create enhanced SiGe models using advanced Spectral Analysis software based on Design of Experiment (DoE) wafers with wide range split. Five different Ge% process conditions are considered and multiple correlations created to report Ge% with less than 1% absolute offset to X-ray Diffraction (XRD) reference tool. The final measured result also shows excellent Ge% stability (STDEV ~ 0.13%) even when multi-SiGe thicknesses are changed.

Several layers with different Ge% and thicknesses are grown within SiGe multi-layers stacks in order to get desired device performance. Figure 1 (a) and 1 (b) also show the optical models of traditional two layers and newly optimized individual six layer stacks respectively.

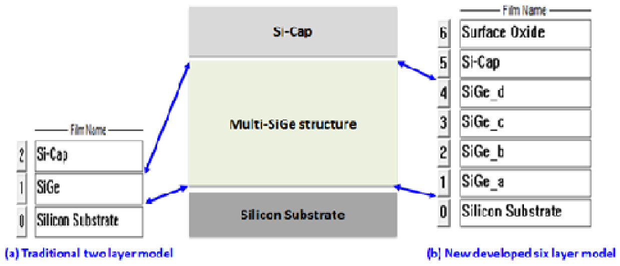

Figure 1: Schematic structure of (a) traditional two layer model; (b) newly developed six layers model for complex mulit-SiGe structure measurement

Figure 2 shows SiGe, Si-Cap thicknesses and Ge% correlations with Transmission Electron Microscopy (TEM) and XRD using coarse recipe for the wide range DoE wafers. R^2 is larger than 0.95 for all critical dimensions measurements, demonstrating the ability of SE to track the reference tools very well and showing sensitivity to SiGe multi-layer thicknesses and Ge% variations.

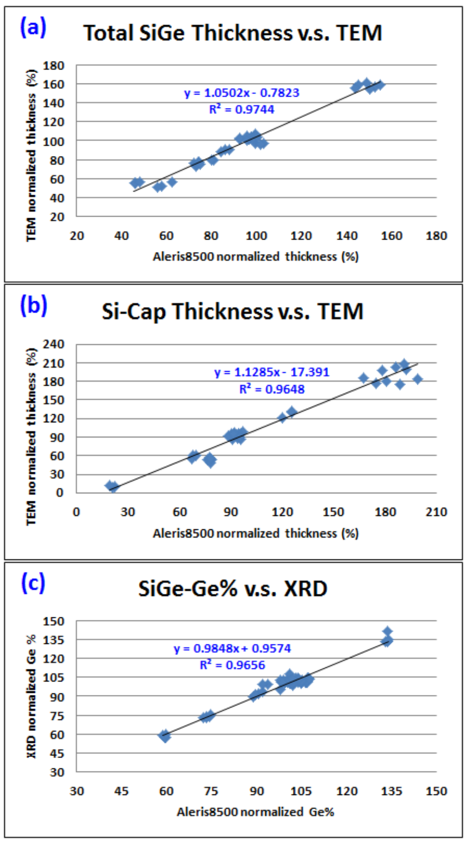

Figure 2: SE measured results compared to reference tool data (TEM and XRD): (a) total SiGe thickness; (b) Si-Cap thickness; (c) Ge%

Typical Ge% variations are originated from process tool instability. Therefore gas flows and temperatures were set to five different conditions to simulate drift on the process tools. Figure 3 (a) shows the coarse recipe SE measurements results compared to XRD. The coarse recipe displayed up to 4% variation, much larger than ~ 1% variation on XRD.

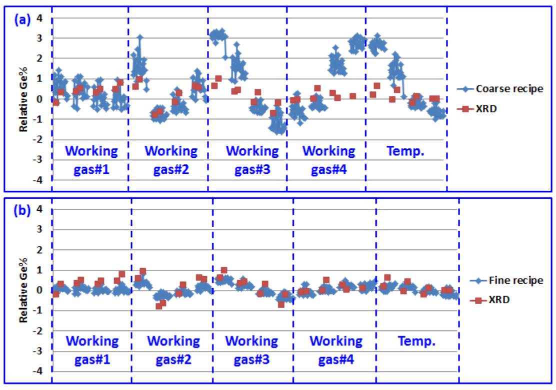

Figure 3: SE measured results compared to reference tool data (XRD) across five different process conditions: (a) Coarse recipe results; (b) Fine recipe results using multiple correlation

This paper will explain changes that were made to the SE optical algorithm to generate a fine recipe. The fine recipe SE measurement results for the five different process conditions are shown in Figure 3 (b) and demonstrate that the SE measurements now track the XRD results.