Scanning Transmission Electron Microscopy Investigations of the Structure and Stability of Alternative Gate Dielectrics

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Results on stability and interface structures of thin film dielectrics, such as ZrO_2, HfO_2, Y_2O_3 and their alloys with SiO_2 or Al_2O_3, currently under investigation to replace SiO_2 in CMOS, will be presented. High-resolution analytical capabilities are essential in analyzing the stability of these ultrathin layers. We apply electron energy-loss spectroscopy (EELS) and atomic resolution Z-contrast imaging in scanning transmission electron microscopy to dielectric layers after high temperature anneals necessary for CMOS device processing. The composition and bonding across the gate dielectric is measured with sub-nanometer spatial resolution. We analyze interface reaction mechanisms under conditions of oxygen excess, such as interfacial SiO_2 and silicate formation, and under reducing conditions (silicide formation). We also present thermodynamic modeling of phase separation in alloys with SiO_2. We discuss the influence of film nonstoichiometry, in particular oxygen excess and oxygen deficiency, on the reaction mechanisms. We also use x-ray absorption spectroscopy and EELS to analyze the unoccupied states, which determine the conduction band offsets with silicon. This research was performed in collaboration with J.-P. Maria, A. Kingon, G. Parsons (NCSU), P. Lysaght (Sematech) and T.P. Ma (Yale) and funded by the SRC/Sematech Front End Process Center.