Synchrotron Radiation X-Ray Photoelectron Spectroscopy Applied to Advanced High-k Metal Gate Stacks

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ABSTRACT

The integration of metal gate/high-k dielectric structures for the 32 nm-generation of CMOS devices and beyond requires a thorough physico-chemical characterization of the stacks with appropriate experimental techniques in order to help further optimizations. X-ray photoelectron spectroscopy (XPS) is widely used for this purpose. Laboratory XPS instruments, which typically use Al Kα (1486.6 eV) or Mg Kα (1253.6 eV) lines for excitation, give very useful information. However the capabilities of laboratory systems are typically limited by their energy resolution and surface sensitivity. The use of synchrotron radiation overcomes these obstacles thanks to: an improved spectral width ranging from hard to soft x-ray domain, a tunable energy and high brightness source. Then, synchrotron radiation allows the non-destructive in-depth analysis of nanoscale buried layers and interfaces typically present in CMOS structures.

Using both soft (S-XPS) and hard (HAXPES) x-ray photoelectron spectroscopy, a detailed analysis of the chemical and electronic properties of technologically relevant TiN/HfSiON/SiON/Si gate stacks (i.e. processed in “integration like” conditions) will be presented. In these structures, an ultra-thin LaOx or AlOx capping layer is inserted in between the TiN gate and the HfSiON dielectric. Measurements were performed at the Soleil synchrotron facility on beamline TEMPO for S-XPS and at the ESRF on beamline ID32 for HAXPES. The combination of these techniques enables us to successfully probe the targeted interfaces, without deprocessing the top TiN metal gate layer keeping the integrity of the full stack. These analyses not only have confirmed the formation of interfacial silicate layers but, they have also assessed their thermal stability. In addition, based on the core level energy shifts, we highlight band offsets, which strongly indicate the presence of an interfacial dipole and/or a fixed charge effect. The results of the different analyses will be discussed and related to the electrical properties of the devices.

FIGURE 1. Si 1s core-level spectra obtained with HAXPES on TiN/LaOx/HfSiON/SiON/Si gate stacks before (left) and after (right) high-temperature activation annealing

Keywords: Synchrotron radiation, S-XPS, HAXPES, High-k, CMOS