Elemental Depth Profiling Of Ultra Thin High-k Material Stacks By Full Spectrum ToF-SIMS And LEIS

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The Microelectronics technological nodes at 32 nm and below require extreme dimensional scaling which is impossible to obtain with classical materials for CMOS integration. High-k materials, with their reduced EOT, are considered as one of the answers to this problem.[1] However, the electrical properties of the final High-K / Metal Gate devices greatly depend on the stoichiometry and on the in-depth distribution of the high-k layer constituent elements.[2] Accurate concentration depth profiling of these materials is thus essential. In this work we investigate the feasibility of a quantitative depth profiling with Time of Flight Secondary Ion Mass Spectrometry (ToF-SIMS) and Low Energy Ion Scattering (LEIS). SIMS or ToF-SIMS characterization of high-k material stacks is usually hampered by matrix effects.[3] Here, we use a Full Spectrum protocol for ToF-SIMS data acquisition and treatment which reduces matrix effects and allows simultaneous quantitative profiling for all matrix elements.[4-5]

Three samples were prepared on Si substrates and studied with the CEA-Leti TOF.SIMS 5 instrument, and with a Qtac LEIS instrument, both from ION-TOF GmbH. Each sample is representative of different steps in the elaboration of a typical high-k stack: first a thin SiON(1.5 nm) layer, then an HfSiON(1.7 nm)/SiO_2(1.2 nm) stack, and finally an HfSiON(1.7 nm)/SiON(1.5 nm) stack. SiO_2 is formed by oxidation of the silicon substrate with in-situ steam generation at 1025°C and hafnium silicate is deposited by MOCVD. Nitridation of both pedestal SiO_2 and hafnium silicate are carried out by a plasma nitridation followed by a 1000°C Rapid Thermal Anneal.

An example of complete high-k material stack quantitative profiling by ToF-SIMS is shown in figure 1. The ToF-SIMS profile seems accurate since it yields a material composition of $Hf_{0.6}Si_{0.38}O_{1.7}N_{0.31}$, in agreement with the nominal specifications. However, only the comparison of the results obtained with both instruments will allow us to draw conclusions on the accurate in-depth composition of these stacks. Profiles are thus compared and both instruments accuracy is assessed. The typical features of each technique in terms of depth resolution, sensitivity and depth of information are also investigated.

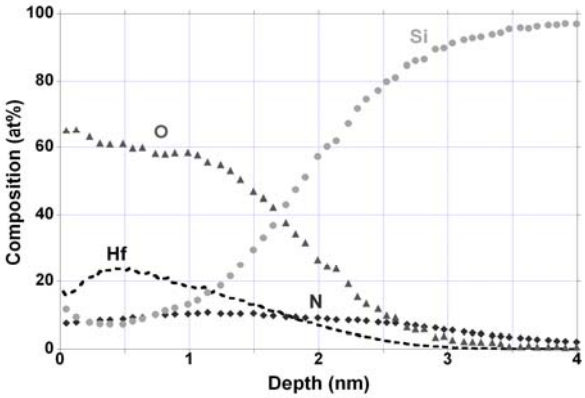

FIGURE 1. Full Spectrum ToF-SIMS profiles of an HfSiON(1.7 nm)/SiON(1.5 nm) stack deposited on Si.

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