Effect of HfO_2 Deposition Rate on Interfacial Layer Thickness

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Many high permittivity oxides have been studied as alternate gate insulators for submicron field effect transistors, attempting to reduce the extremely large gate leakage by allowing a larger thickness than ultrathin SiO_2. HfO_2 with a permittivity of 17 has been deposited from $Hf(NO_3)_4$ at 350 °C and about 4 torr in an inert ambient[1]. However, an interfacial oxynitride layer with a permittivity of 5 has been demonstrated to form. One probable mechanism is the thermal reaction of the precursor decomposition byproducts, NO and NO_2 and the silicon substrate. In order to minimize the total equivalent oxide thickness of the gate stack, it becomes essential to control the thickness of the interfacial layer. We show that one approach is to reduce the HfO_2 deposition time.

HfO_2 films were grown from hafnium nitrato at different deposition time: 5 seconds, 10 seconds and 15 seconds. To allow useful thickness at these short growth times, our CVD system was modified to dramatically improve the precursor transport to the wafer. The film thickness was mapped and then used to build Pt gate capacitors. C-V characteristics were measured by a HP 4294A Precision Impedance Analyzer and EOTs were extracted from John Hauser's device model[2]. Figure 1 shows the EOT as a function of physical thickness. The interfacial layer thickness increases with the deposition time. This trend is well described by the Mott-Cabrera mechanism[3], which models the low temperature oxidation of silicon. To verify this dependence, the data from these three runs, as well as HRTEM measurements from slower growths, were fitted into Elovich Equation[4] as shown in Figure 2. Although there is some scatter, a reasonably good fit is obtained. The permittivity of the film at a very short deposition time is lower. We believe this is related to the reduced crystallinity of the film at rapid deposition. The permittivity can be recovered to 16 by annealing the 5-second film in an inert ambient at 700 °C for 10 seconds. Even though the interfacial layer increased by 2 Å, it was still much less than the slow process.

The leakage current density of rapid deposited HfO_2 (60 nm/minute) has been compared with SiO_2 and HfO_2 film deposited at a lower rate (2 nm/minute), as shown in Figure 3. At the same EOT, the rapid film shows a leakage of an order smaller than the slow one. The intercepts with SiO_2 curve correspond closely to their interfacial layer thickness. In summary, we believe that rapid deposition of high permittivity films may be a reasonable approach to limiting the growth of interfacial oxides that limit the EOT that can be obtained with these materials.

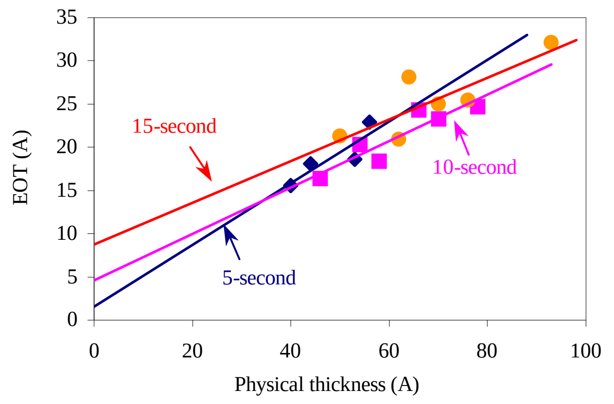

Figure 1 EOT for HfO_2 at different deposition time as a function of the physical thickness of the HfO_2

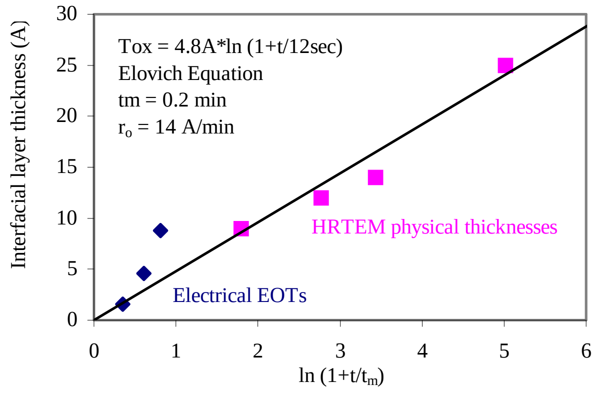

Figure 2 Comparison of interfacial layer thickness with Elovich equation

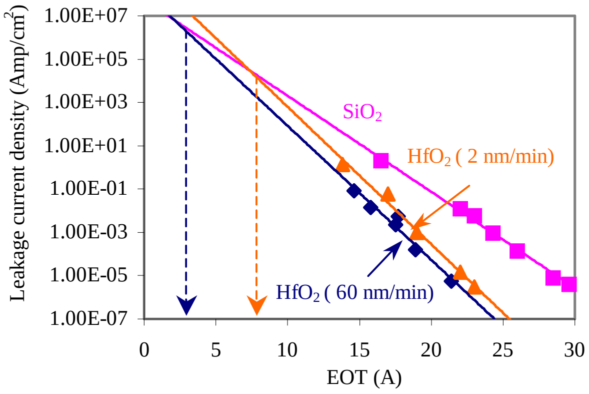

Figure 3 Comparison of leakage current density of HfO_2 films at different deposition rate

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