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# In-line electrical metrology for high-k gate dielectrics deposited by Atomic Layer CVD


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Industry road maps for CMOS technology indicate that conventional thermal silicon oxide gate dielectrics rapidly will run out of steam because leakage current requirements cannot be met. This issue can be addressed by introducing high-k dielectrics such as $Al_2O_3$, $HfO_2$, $ZrO_2$ or possibly their aluminates or silicates. Fully functional transistors with high-k films deposited by Atomic Layer Chemical Vapor Deposition (ALCVD™ [1]) are already reported by various groups [2,3,4,5].
Introduction of high-k gate stacks also means appearance of new film metrology challenges. Accurate film thickness measurements and rapid turn around time electrical analysis are highly desirable for high-k process development, tuning and monitoring. In this paper we will evaluate characterization of high-k gate dielectrics using a KLA-Tencor Quantox in-line electrical metrology tool.
For the purpose of the test typical AlZrO based high-k gate dielectrics were made with an ASM Polygon™ 8200 [1] gate stack cluster tool. A 0.5 nm $SiO_2$ interface layer was grown on p-type device quality wafers, followed by ALCVD deposition of the high-k layer, annealing in $N_2$ and in forming gas. Three different AlZrO layer thicknesses (30, 50, 100 ALCVD cycles) were investigated. For comparison with high frequency C-V, duplicate wafers were made and further processed into capacitors with TiN electrodes.
In Fig. 1 the high frequency C-V curves are shown as measured on the TiN metal electrode capacitors. Well developed C-V curves are obtained and the observed accumulation capacitance clearly increases with decreasing AlZrO thicknesses. A small bump is visible at the lower end of the C-V curves, indicative of some slow traps in the layers. Hauser fits to the data indicate equivalent oxide thicknesses (with QM correction) in the range 1.21 nm to 3.03 nm, see Table 1.
The Quantox operates by depositing charge on the surface and measuring for each charge the surface voltage with a Kelvin probe (quasistatic measurement). In Fig. 2 and Fig. 3 the obtained $Q_{dep}$-$V_{surf}$ curves and C-$V_{surf}$ curves are shown ($C=dQ_{dep}/dV_{surf}$). Again well developed C-V curves are obtained, characterized by a relatively steep slope in depletion and saturation of the capacitance in accumulation. The capacitances measured in accumulation are very similar to those measured by high frequency C-V. A remarkable result is that despite the quasistatic nature of the measurement and the very small EOTs of the layers no signs of charge leakage are observed. The extremely low leakage currents for small EOT are typical for the ALCVD high-k films.
In Fig. 4 a plot is shown in which the high frequency C-V curve and the quasistatic C-V curve of the 50 cycle AlZrO sample are combined. The high frequency curve has been shifted 1.3V towards higher voltages to compensate for the work function differences of the respective electrodes (TiN and Quantox). The plot shows that accumulation capacitances of the two methods are very similar. The quasistatic C-V curves obtained by the Quantox has a steeper slope in the depletion part, indicating that the high frequency method is probing some traps that are not seen in the quasistatic Quantox measurement.
The Quantox C-V data can be modeled well by the Hauser method. Table 2 lists the obtained EOT (with QM correction) and COT (accumulation capacitance) and compares them with the "GateTox™" [6] data (representing accumulation capacitance) extracted by the Quantox software. Excellent agreement is obtained for all three layers confirming that on small-EOT ALCVD high-k layers in-line electrical metrology can be used as an alternative for much more time consuming capacitor tests.
In the paper we will further elaborate on other parameter extractions of the quasistatic measurements such as interface and bulk charge and present some results for other high-k oxides ($Al_2O_3$, $HfO_2$).

**References**


[1] ALCVD™, Polygon™ 8200 are trademarks of ASM International nv.
[2] D.A. Buchanan et.al., IEDM 2000.
[3] K. Torii at.al., IWGI2001.
[4] Y. Kim at.al., IEDM2001.
[5] J.M. Hergenrother at.al, IEDM2001.
[6] GateTox™ is a trademark of KLA-Tencor corp.


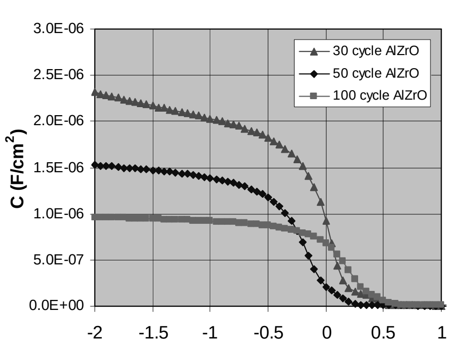


Fig 1: MOSCAP high frequency C-V curves of AlZrO based high-k stacks of three different thicknesses.

Table 1: Ellipsometry and high frequency C-V data of AlZrO based high-k gate stacks.

| ALCVD cycles | Optical Thickness (nm) | RI (633 nm) | EOT (nm) |
|---|---|---|---|
| 30 | 3.42 | 1.82 | 1.21 |
| 50 | 5.62 | 1.84 | 1.82 |
| 100 | 11.1 | 1.86 | 3.03 |

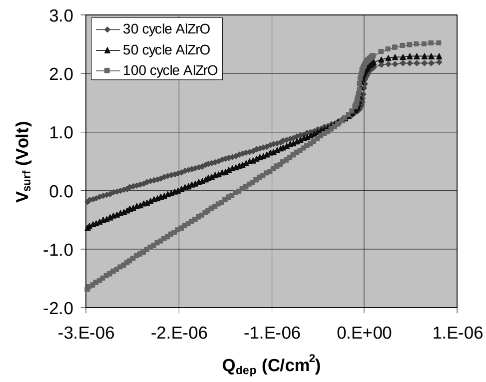


Fig. 2: Quantox $Q_{dep}$-$V_{surf}$ curves for high-k gate dielectric films of three different thicknesses.

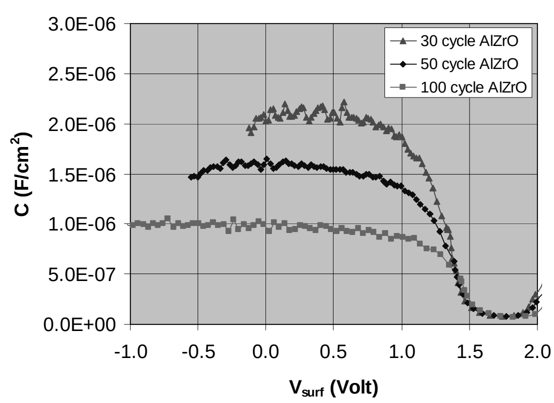


Fig. 3: Quantox C-$V_{surf}$ curves for high-k gate dielectric films of three different thicknesses.

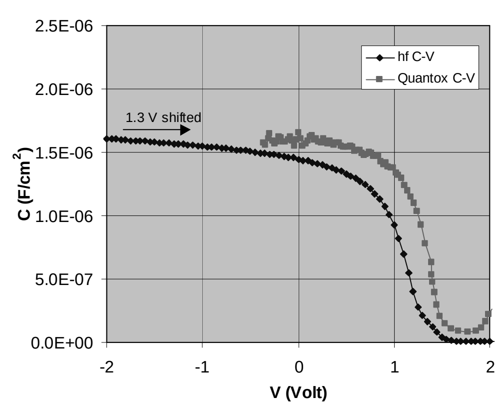


Fig 4: MOSCAP high frequency and Quantox quasistatic C-V curve for the 50 cycle AlZrO sample. The high frequency curve is shited 1.3 V towards higher voltages.

Table 2: Ellipsometry and high frequency C-V data of AlZrO based high-k gate stacks.

| ALCVD cycles | Optical Thickness (nm) | RI (633 nm) | EOT Hauser (nm) | COT Hauser (nm) | gateTox Quantox (nm) |
|---|---|---|---|---|---|
| 30 | 3.59 | 1.82 | 1.22 | 1.62 | 1.64 |
| 50 | 5.65 | 1.83 | 1.83 | 2.23 | 2.21 |
| 100 | 10.9 | 1.86 | 3.18 | 3.58 | 3.61 |