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Ultrathin SiO_2 Films Grown by Atomic Layer Deposition Using Tris(dimethylamino)silane and Ozone

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SiO_2 is widely used for optical and electronic applications. The highest quality SiO_2 is formed by thermal oxidation of Si at temperatures over 800ºC in dry O_2. However, thermal oxide can only be grown on Si substrates at high temperatures, which limits its applications. For examples, thin-film MOS transistors used for flat-panel displays need gate insulators deposited on thin-film materials; various sensor structures and microelectromechanical systems (*MEMS*) need high-quality SiO_2 film deposited on different substrates other than silicon. Atomic Layer Deposition (ALD) could grow high-quality conformal SiO_2 films on non-silicon substrates and on high aspect-ratio pores and nanostructures. In the published researches, there is rare work on thin ALD SiO_2 films under 100 cycles (<5nm). In addition, most publications dealt with ALD growth and only limited information is available on electrical properties. In this paper, we study extensively the physical and electrical properties of ultrathin ALD SiO_2 films (<3.5 nm) grown using Tris(dimethylamino)silane (TDMAS) and Ozone.

H-terminated Si surface was achieved by immersing substrates into BOE (buffered oxide etch) solution. SiO_2 films were deposited by ALD at 100ºC, 200ºC and 300ºC using TDMAS and ozone as precursors. MOS capacitors using ALD SiO_2 as gate oxide were fabricated using the Ni metal gate and wet etching process. Fig. 1 shows the growth linearity of ALD SiO_2. All the depositions at 100ºC, 200ºC and 300ºC show excellent linearity, which suggests atomic-layer-by-atomic-layer deposition. At 100ºC, the deposition rate was ~0.2Å/cycle; at 200ºC, the rate was ~0.7Å/cycle; at 300ºC, the rate was ~0.6Å/cycle. The dependence of growth rate on the temperature is caused by the endothermic nature of the dissociative chemisorptions of TDMAS on substrate, and energy needs to be provided to activate and maintain the chemical reaction. In our experiment conditions, 200ºC reaction temperature is enough to provide necessary thermal energy.

Fig. 2 and 3 show the C-V and I-V curves of MOS capacitors using 50, 70 and 90 cycles of ALD SiO_2 at 100ºC as dielectric. The equivalent oxide thickness (EOT) of the ALD SiO_2 films is 2.34 nm, 2.68 nm and 2.89 nm. The gate leakage currents at $V=V_{FB}+1V$ are marked in Fig. 3, and they match well with that of the thermally grown SiO_2. The leakage current, which is direct tunneling current, increases exponentially as SiO_2 thickness decreases, i.e. every 2Å decrease in the thickness results in 1 order-of-magnitude leakage-current increase. This is the typical property of high quality thermal SiO_2 films thinner than 3.5 nm. The gate leakage current of SiO_2 films (<3.5 nm) deposited at 200ºC and 300ºC is also comparable with that of thermally grown SiO_2.

This suggests that SiO_2 deposited by ALD can achieve gate leakage current comparable with that of thermally grown SiO_2. The appealing electrical properties of ALD SiO_2 enable its potential applications as high-quality gate insulators for thin-film MOS transistors, and insulators for sensor structures and nanostructures on non-silicon substrates.

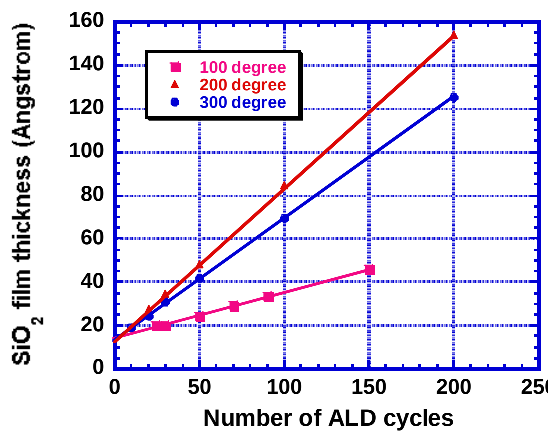

Figure 1 Linearity of the atomic layer deposition of SiO_2 at 100ºC, 200ºC and 300ºC. Film thickness was obtained by spectroscopic ellipsometry.

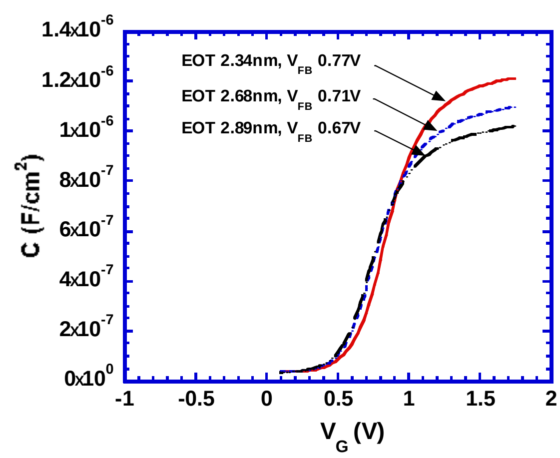

Figure 2 High frequency (100 KHz) Capacitance-Voltage (C-V) curves of MOS capacitors using ALD SiO_2 at 100ºC as dielectric. The SiO_2 thin films were deposited for 50, 70 and 90 cycles.

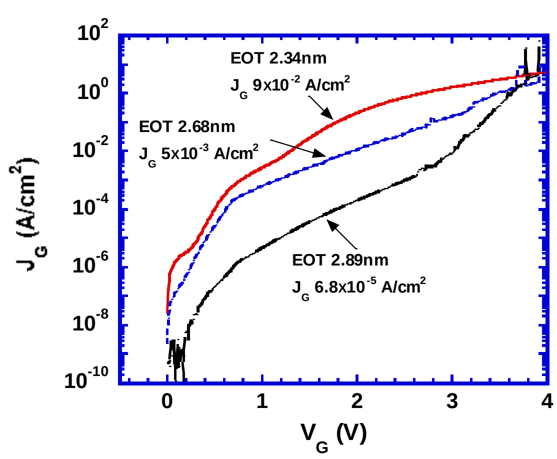

Figure 3 Current-Voltage (I-V) curves of MOS capacitors using ALD SiO_2 at 100ºC as dielectric.