W-Gate MOSFETs with Ta₂O₅/SiO₂ Gate Insulator

M. Nakata and H. Shinriki

Central Research Laboratory, Hitachi Ltd., Kokubunji, Tokyo 185, Japan

A multilayer gate insulator of Ta₂O₅/SiO₂ equivalent to 5nm thick SiO₂ has been successfully developed. Its interface trap density is 4x10¹⁰ eV⁻¹cm⁻², its mobility is 500cm/Vs, and its TDDB lifetime is 4-5 decades longer than that of SiO₂. A W-metal gate was applied to maintain thermal stability against chemical reaction with Ta₂O₅ film up to 1000°C and realize high performance due to the low resistance of the W film.

According to the scaling law, scale down MOSFETs under 0.3μm channel length, a thickness of thermally grown oxide (th-SiO₂) must be reduced to under 5nm. However, it is difficult to thin a conventional th-SiO₂ because 1) too many defects cause initial breakdown, 2) direct tunneling conduction cause an increase of leakage current [1].

A highly reliable 3nm-thick Ta₂O₅/SiO₂ double-layer film has been reported to be promising as a storage dielectric film for DRAMs [2]. To realize a small size MOSFETs, a double-layer film is an attractive substitute for a SiO₂ gate insulator.

NMOSFETs and capacitors made of Ta₂O₅/SiO₂ double-layer were fabricated. The thickness of Ta₂O₅ film ranged from 20 to 30nm, and the thickness of SiO₂ under the Ta₂O₅ film ranged from 2nm to 25nm. Because of high dielectric constant (ε=22) of Ta₂O₅, the resultant equivalent SiO₂ thickness was from 5 to 35nm. The gate length varied from 0.6 to 10 μm with a gate width of 10μm. The fabrication process is illustrated in Fig.1. After Ta₂O₅ deposition with reactive rf-magnetron sputtering, these films were subjected to weakspot oxidation at 800°C in a dry oxygen atmosphere to reduce initial defect density [3]. In this case, little growth of the bottom oxide was observed. Next, a tungsten film was sputter deposited on the Ta₂O₅/SiO₂ film and patterned. Arsenic implantation through the Ta₂O₅/SiO₂ films was performed to form source and drain, and the wafers were annealed.

Significant results are described below. The n-MOSFET characteristics with a Ta₂O₅(20nm)/SiO₂(2nm) film (5nm SiO₂ equivalent thickness) are shown in Figs.2 and 3. The subthreshold slope is approximately 70mV/decade, not inferior to an FET with a thermally grown SiO₂ gate insulator. Excellent subthreshold slope is obtained, while it implies the very low interface states density of Ta₂O₅/SiO₂/Si structure. The interface trap density measured by the quasi-static and high-frequency C-V method using the capacitor is approximately 4x10¹⁰ eV⁻¹cm⁻². This is the same level as that of a th-SiO₂ capacitor. Figure 3 shows the saturation transconductance versus SiO₂ equivalent thickness of the gate insulator(5-30nm), compared with an n-MOSFET having a gate insulator made of a th-SiO₂. The solid lines shown in the figure indicate the dependence of Gm of 400, 500, 600 on SiO₂ equivalent thickness. These results show that both devices with a Ta₂O₅/SiO₂ gate insulator and with a th-SiO₂ gate insulator exhibit approximately 500cm²/Vs from 5nm to 30nm equivalent thickness. These MOSFETs showed even better immunity to channel-hot-electron injection (not shown here). Figure 4 shows the TDDB characteristics of Ta₂O₅/SiO₂ film, compared with that of th-SiO₂ film. The lifetime to 50% cumulative failure is 4-5 decades longer than that of the th-SiO₂ film. Figure 5 shows the equivalent thickness dependence on the defect density for initial breakdown. It is very evident that the Ta₂O₅/SiO₂ films which received weakspot oxidation have a very small defect density even at a thickness of 5nm.

In conclusion, innovative W-gate MOSFETs with 5nm-thick Ta₂O₅/SiO₂ gate insulators have been developed. This may be a most attractive candidate for deep submicron MOS devices.

Fig. 1. Fabrication process for a W-gate Ta$_2$O$_5$/SiO$_2$ MOSFET.

Fig. 2. Drain current and transconductance as a function of gate voltage in W-gate MOSFET with Ta$_2$O$_5$/SiO$_2$(20/2nm) gate insulators ($V_D=0.1V$).

Fig. 3. Dependence of $G_m$ on SiO$_2$ equivalent thickness.

Fig. 4. Dependence of defect density on SiO$_2$ equivalent thickness at SiO$_2$(1) and Ta$_2$O$_5$/SiO$_2$.

Fig. 5. TDDB characteristics of Ta$_2$O$_5$/SiO$_2$ film and SiO$_2$. 