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W-Gate MOSFETs with Ta_2O_5/SiO_2 Gate Insulator

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A multilayer gate insulator of Ta_2O_5/SiO_2 equivalent to 5nm thick SiO_2 has been successfully developed. Its interface trap density is $4\times10^{10}eV^{-1}cm^{-2}$, its mobility is 500cm/Vs, and its TDDB lifetime is 4-5 decades longer than that of SiO_2. A W-metal gate was applied to maintain thermal stability against chemical reaction with Ta_2O_5 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-SiO_2) must be reduced to under 5nm . However, it is difficult to thin a conventional th-SiO_2 because 1) too many defects cause initial breakdown, 2) direct tunneling conduction cause an increase of leakage current [1].

A highly reliable 3nm-thick Ta_2O_5/SiO_2 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 SiO_2 gate insulator.

NMOSFETs and capacitors made of Ta_2O_5/SiO_2 double-layer were fabricated. The thickness of Ta_2O_5 film ranged from 20 to 30nm, and the thickness of SiO_2 under the Ta_2O_5 film ranged from 2nm to 25nm. Because of high dielectric constant ($\varepsilon=22$) of Ta_2O_5, the resultant equivalent SiO_2 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 Ta_2O_5 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 Ta_2O_5/SiO_2 film and patterned. Arsenic implantation through the Ta_2O_5/SiO_2 films was performed to form source and drain, and the wafers were annealed.

Significant results are described below. The n-MOSFET characteristics with a Ta_2O_5(20nm)/SiO_2(2nm) film (5nm SiO_2 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 implies the very low interface states density of $Ta_2O_5/SiO_2/Si$ structure. The interface trap density measured by the quasi-static and high-frequency C-V method using the capacitor is approximately 4×10^{10} $eV^{-1}cm^{-2}$. This is the same level as that of a th-SiO_2 capacitor. Figure 3 shows the saturation transconductance versus SiO_2 equivalent thickness of the gate insulator(5-30nm), compared with an n-MOSFET having a gate insulator made of a th-SiO_2. The solid lines shown in the figure indicate the dependence of Gm of 400, 500, 600 on SiO_2 equivalent thickness. These results show that both devices with a Ta_2O_5/SiO_2 gate insulator and with a th-SiO_2 gate insulator exhibit approximately 500cm^2/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 Ta_2O_5/SiO_2 film, compared with that of th-SiO_2 film. The lifetime to 50% cumulative failure is 4-5 decades longer than that of the th-SiO_2 film. Figure 5 shows the equivalent thickness dependence on the defect density for initial breakdown. It is very evident that the Ta_2O_5/SiO_2 films which received weakspot oxidation have a very small defect density even at a thickness of 3nm.

In conclusion, innovative W-gate MOSFETs with 5nm-thick Ta_2O_5/SiO_2 gate insulators have been developed. This may be a most attractive candidate for deep submicron MOS devices.

[1] T. Kusaka, et al., Extended Abstracts of 18th SSDM., 1986, p463.
[2] H. Shinriki, et al., Proc. Symp. VLSI Thch., 1989, p25.
[3] Y. Nishioka, et al., J. Electrochem. Soc., Vol.134, 1987, p134.

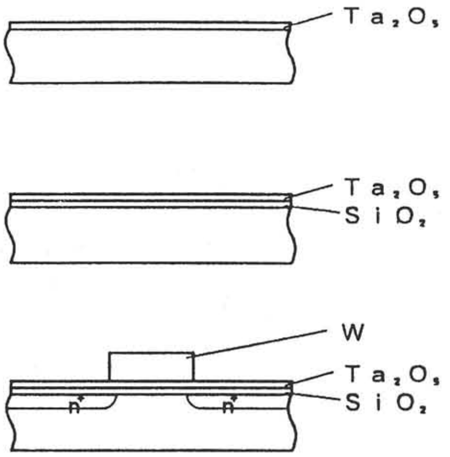

Fig.1. Fabrication process for a W-gate Ta_2O_5/SiO_2 MOSFET.

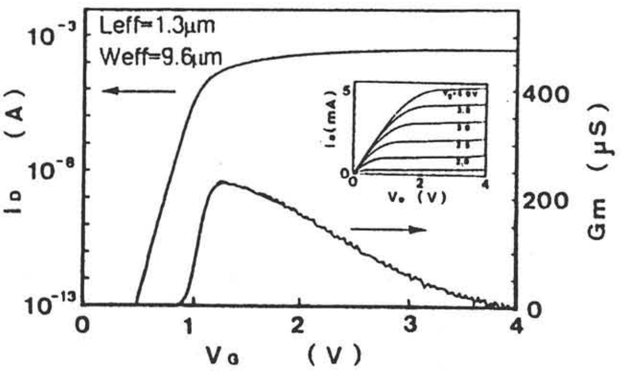

Fig.2. Drain current and transconductance as a function of gate voltage in W-gate MOSFET with Ta_2O_5/SiO_2(20/2nm) gate insulators.(V_D=0.1V)

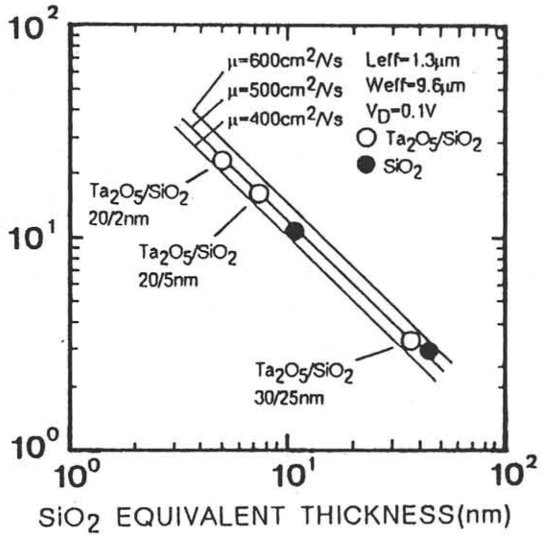

Fig.3. Dependence of Gm on SiO_2 equivalent thickness.

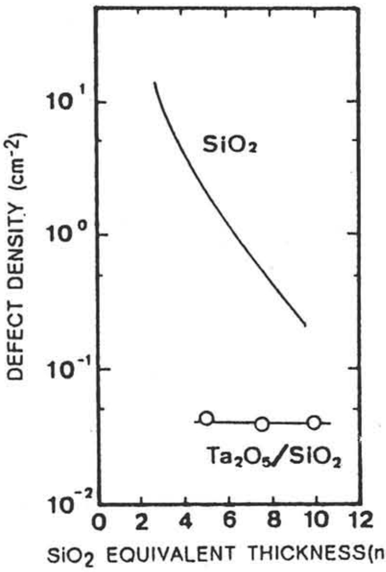

Fig.4. Dependence of defect density on SiO_2 equivalent thickness at SiO_2[1] and Ta_2O_5/SiO_2.

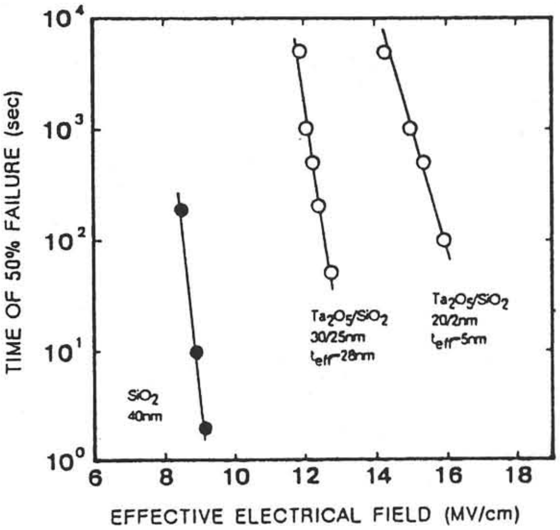

Fig.5. TDDB characteristics of Ta_2O_5/SiO_2 film and SiO_2.