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Effect of Oxide Layer in Metal-Oxide-Semiconductor Systems

Jung-Chuan Fan[1,a] and Shih-Fong Lee[1,b]
[1]Department of Electrical Engineering, Da-Yeh University, Changhua, Taiwan 51591
[a]fanjc@mail.dyu.edu.tw[1], [b]sflee@mail.dyu.edu.tw

Abstract. In this work, we investigate the electrical properties of oxide layer in the metal-oxide semiconductor field effect transistor (MOSFET). The thickness of oxide layer is proportional to square root of oxidation time. The feature of oxide layer thickness on the growth time is consistent with the Deal-Grove model effect. From the current-voltage measurement, it is found that the threshold voltages (Vt) for MOSFETs with different oxide layer thicknesses are proportional to the square root of the gate-source voltages (Vgs). It is also noted that threshold voltage of MOSFET increases with the thickness of oxide layer. It indicates that the bulk effect of oxide dominates in this MOSFET structure.

1. Introduction

After the discovery of MOSFET, the oxide layer was an important electrical insulator in the metal-oxide-semiconductor system. A special effect of oxide layer in a small scale device is not avoiding the problems of chemical and physical properties. Reducing the oxide layer thickness will lead to problems of tunneling leakage current through the source/drain and substrate. [1,2] Defect may also occur in thin oxide film. The gate oxide leakage is observed in MOSFET systems. This can be attributed to tunneling assisted by the traps in the interface between oxides and semiconductor.[3-5] In this defect situation, it depicts the relationship between the threshold voltage and the gate oxide thickness of MOSFET. The threshold voltage of the MOSFET is a function of oxide layer thickness, which states that the threshold voltage of the device is increased if oxide thickness is increased.

In this study, we present the oxide layer effect of MOS systems which were fabricated at the low pressure grown by rapid thermal chemical vapor deposition (RTCVD). The dependence of oxide thickness on growth time can be describes by Deal-Grove model. The relationship between square of threshold voltage and the gate-source voltage approaches a very strong linear dependence. It indicates a strong effect of gate leakage in the MOS systems.

2. Experimental Details

Silicon wafers were used as the substrates for MOSFETs. We used the standard method to clean the surface of silicon substrates. The silicon substrates were exposed in the

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* Corresponding author:fanjc@mail.dyu.edu.tw

hydrofluoric acid (HF) solution for a short time in order to remove native silicon dioxide. Place the silicon substrates in the warm acetone bath for 10 minutes. The samples were rinsed in deionized water and blew dry with compressed nitrogen gas.

The oxide layers of various thicknesses were fabricated by varying the deposition time (3hr, 6hr and 12hr) for RTCVD growth. The oxygen ambient pressure in the RTCVD quartz chamber was maintained at 5 torr with mass flow controller meter. The temperature of oxide layers grown was controlled to 900 °C at the different oxidation times.

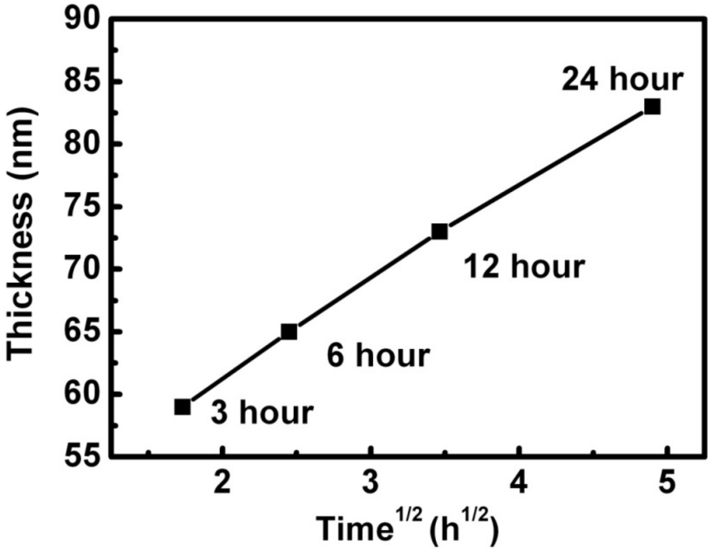

Fig. 1 The thickness of oxide layer as a function of oxidation time.

In the lithography process, wet etching and deposition were used to achieve the field effect transistor structure. Subsequently, aluminum contacts were deposited by a thermal evaporation system. Field-effect scanning electron microscopy (FE-SEM) was used to observe the surface morphology of oxide layers. The composition of oxide layer was determined by energy dispersive X ray spectroscopy (EDS). The thickness of oxide layer was determined by alpha step measurement. And the thickness dependence of oxide layers on the electrical properties of MOSFET were studied by current-voltage measurement.

3. Results and Discussion

Fig. 1 shows the measured thickness of oxide layers as a function of oxidation time. The thickness of oxide layer is proportional to square root of oxidation time indicating that the growth of oxide is in the mass transfer (diffusion) limited regime as predicted by Deal-Grove model. The relation of oxide layer thickness on the varying deposition time can be reduced to the square root function, *i.e.* $\mathbf{x_0} \cong \sqrt{\boldsymbol{B} \cdot \boldsymbol{t}}$, where B is the so-called parabolic rate constant, x_0 is oxide layer thickness, t is deposition time. The parameter B is estimated to 224 um^2/hr from the figure 1. It reveals that physical mechanism really represents the oxidant diffusion process in the low pressure oxygen ambient growth.

Fig. 2 is the measured I_D-V_{DS} characteristics at various V_{GS} voltages for MOSFET with an oxide layer grown for 12 hours. The increased I_D current at higher V_{GS} voltage is a direct consequence of the channel modulation effect of MOSFET structure. By definition, threshold voltage (Vt) can be determined as the turning-point voltages shown in Fig. 2. When the source-drain voltage V_{DS} below the threshold voltage Vt, the drain current I_D is negative. The threshold voltage has strong relation and serves as a function of gate voltage. It indicates that the gate leakage effect is dominant in these MOSFET systems. The defect in the oxide layer causes the charge trapping which contributes to the leakage current in the drain current I_D. The influence of gate leakage will be increased as the gate voltage is increased. The defect generation in the oxide is probably dependent on the oxide layer thickness.

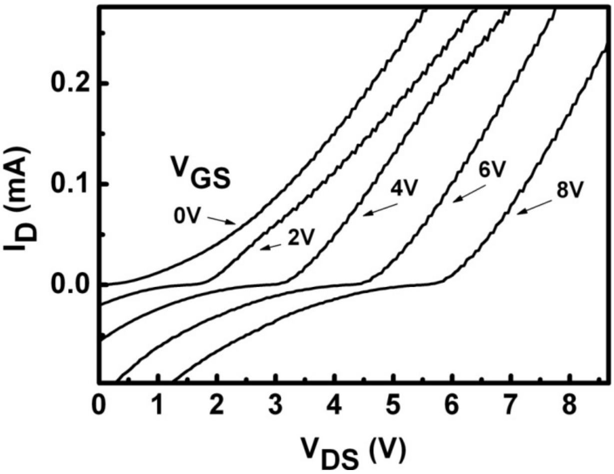

Fig. 2 The I_D-V_{DS} characteristics for MOSFET with an oxide layer grown for 12 hours.

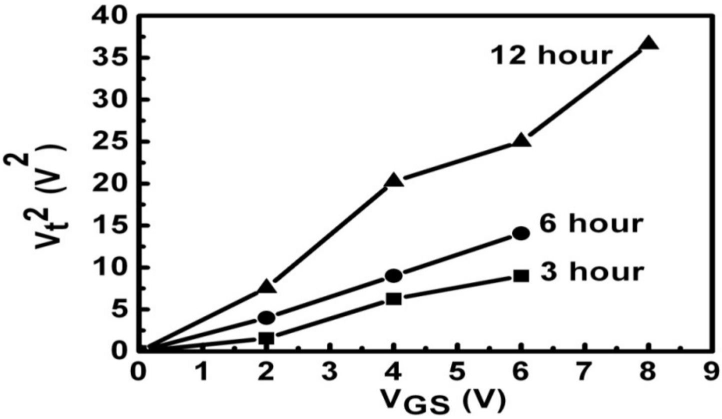

Fig. 3 The relationship of Vt^2 vs. V_{GS} for MOSFETs with oxide layers grown for different times.

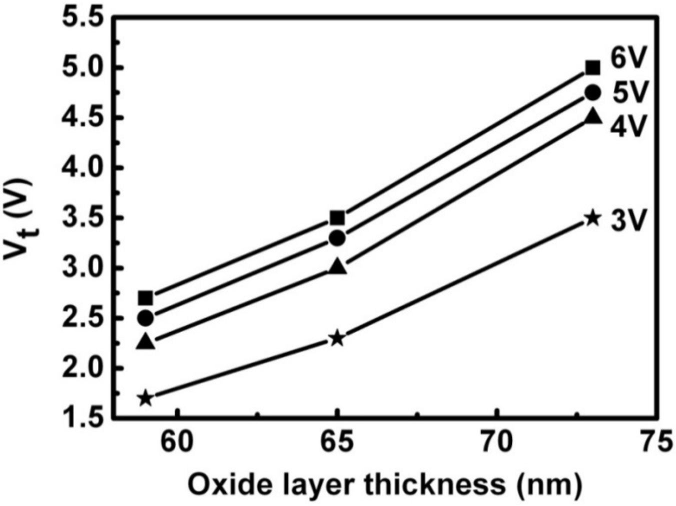

Fig. 4 The relationship of Vt vs. the oxide thickness for MOSFETs at different V_{GS} voltages.

Fig. 3 shows the relationship of Vt^2 vs. V_{GS} for MOSFETs with oxide layers grown for different times. In Fig. 3, Vt^2 seems to vary linearly with V_{GS} with different slopes. Thus, it can be concluded that the threshold voltages (Vt) of MOSFET is proportional to the square root of the gate-source voltages (V_{GS}) regardless of the thickness of oxide layer. However, these results in Fig. 3 exhibit that the oxide thickness dependence of the defect generation is correspond to the observations of Fig. 2.

Fig. 4 shows the relationship of Vt vs. oxide thickness for MOSFETs at different applied V_{GS} voltages. As noted in Fig. 4, the threshold voltage of MOSFET increases linearly with the thickness of oxide layer. This is a strong indication that the bulk effect of oxide dominates in this MOSFET structure. It reveals that the defect generation dependence on the oxide thickness is strong relation to the gate voltage. The defect in the oxide which contributes to the gate leakage is due to the charge tunneling assisted by the traps in the interface between oxides and semiconductor.[6,7]

4. Conclusions

In this work, we investigate the electrical properties of oxide layer in the metal-oxide-semiconductor field effect transistor (MOSFET). The thickness of oxide layer on the growth time is consistent with the results of Deal-Grove model. By analyzing the current-voltage measurement, the threshold voltages (Vt) for MOSFETs with different oxide layer thicknesses are proportional to the square root of the gate-source voltages (V_{GS}).

It is also noted that threshold voltage of MOSFET increases as the thickness of oxide layer increases. It indicates that the bulk effect of oxide dominates in this MOSFET. The threshold voltage has strong relation and serves as a function of gate voltage. The gate leakage effect dominates in our MOSFET systems. The defect generation in the oxide depends on the oxide layer thickness. This can be attributed to the trap assisted tunneling in the interface between oxides and semiconductor.

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