An Accurate Method to Extract and Separate Interface and Gate Oxide Traps by the MOSFET Subthreshold Current

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ABSTRACT

In this paper, an accurate method is used to extract and separate interface and gate oxide traps by the subthreshold current of MOSFET. The xide trap is supposed to result in a turn-on voltage shift in the semi-log plotted transfer characteristics, while interface trap influences subthreshold slope of the device. The above theory is verified by ISE-Dessis simulation. The results demonstrate that this method is effective and accurate for extracting parameters of devices with gate length less than 1 μ m.

Keywords: Interface Trap, Gate Oxide Trap, Subthreshold Current.

1. INTRODUCTION

Gate oxide interface and oxide traps seriously affected the performance and lifetime of MOSFETs.[1,2] For MOSFETs scaling down to submicron region, the effect becomes more and more serious due to the shift of the threshold voltage[3,4] and the degradation of mobility[5,6]. Thus, it is of great importance to extract interface and oxide traps accurately.

Recently, different methods are reported for the study of the interface and oxide traps, including the forward gated-diode method [7,8,9] and Charge Pumping Current methods[10,11]. Most of these methods are focused on the threshold voltage as a monitor of degradation, and are applied in the invert region. However, the accuracy of threshold voltage extraction is highly affected by short channel effect (SCE) and the mobility degradation. Moreover, the threshold voltage is not a physical parameter in today's device model.

In this paper, a method applied in the subthreshold region is proposed to extract and separate the interface and gate oxide traps, which makes the extraction more valid and accurate for devices with small gate lengths. This method is first used to extract the simulation data of ISE-Dessis simulation, and then compared with the method based on the threshold voltage shift for oxide trap extraction with different gate lengths, demonstrating the validity and accuracy of the method applied in the subthreshold region.

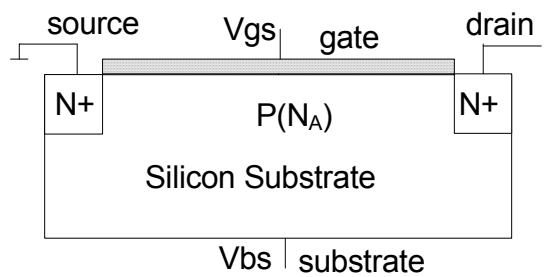

Fig. 1. The schematic structure of the MOSFET in the simulation.

Table 1 Parameters of the device

Parameter	Channel Length	Gate Oxide Thickness	Substrate Doping	N+/P+ Doping
Units	μm	nm	cm^{-3}	cm^{-3}
value	0.35	3	1e17	1e20

2. METHOD

2.1 Structure and parameter description of the

device in the simulation.

The schematic structure of MOSFET for simulation is shown in Fig. 1 and the parameters of the device are shown in Table 1.

2.2 Oxide trap (N_{ot}) extraction

When I_{ds}-V_{gs} curve is plotted in semi-log scale, it is obviously that the increased oxide trap density (N_{ot}) makes the transfer characteristics curve moves in parallel. The simulation result is shown in Fig.2.

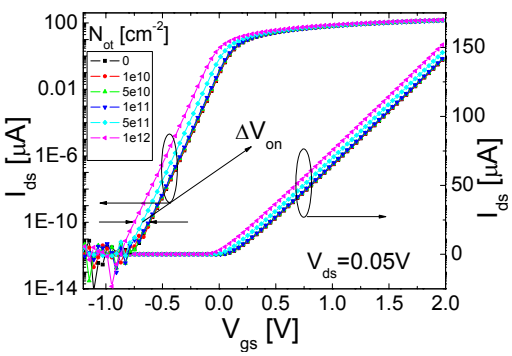

Fig. 2. Transfer characteristics curve with different N_{ot}.

The gate voltage corresponding to a small drain current of 1E-10μA, which is defined as turn-on voltage (V_{on}), is chosen to be a monitor of the impact of oxide traps. The turn-on voltage shift (ΔV_{on}) is expressed in Equ(1)

$$\Delta V_{on} = -\frac{qN_{ot}}{C_{ox}} \tag{1}$$

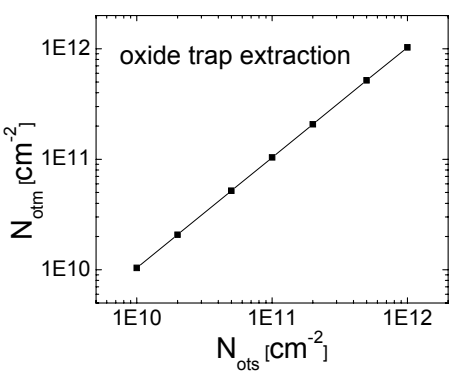

Fig. 3. Comparison between the extraction result and applied N_{ot} based on the simulation result in Fig. 2. N_{otm} is the density of oxide trap extracted from model, while N_{ots} is the density of oxide trap applied in the simulation.

Here N_{ot} is the density of oxide trap, C_{ox} is the capacitance of gate oxide, and q is the charge of single electron. Equ (1) demonstrates the relationship between the reduction of the voltage and concentration of the induced oxide trap. When the concentration of positive oxide traps increases, the transfer characteristics curve moves negatively. Fig.3 shows a good agreement between the extraction result via Equ (1) and the applied simulation N_{ot}.

2.3 Interface trap extraction

Combining with the charge conservation law (Eq(2)), the definition of subthreshold slope is written as Eq (3).

$$C_{ox}(V_g - \varphi_s) = C_D\varphi_s + C_{it}\varphi_s \tag{2}$$

$$S = \frac{dV_{GS}}{d(\lg I_D)} = (\ln 10)\frac{dV_{GS}}{d(\ln I_D)} = (\ln 10)\frac{dV_{GS}}{d(\beta\varphi_s)} = (\ln 10)\frac{kT}{q}(1+\frac{C_D}{C_{ox}}+\frac{C_{it}}{C_{ox}}) \tag{3}$$

$$C_{it} = \frac{dQ_{it}}{dVg} = qD_{it} \tag{4}$$

Where

$$D_{it} = \frac{1}{q}\frac{dQ_{it}}{dE} \tag{5}$$

Thus D_{it} can be extracted as shown in Equ (6)

$$D_{it} = \frac{\Delta S}{qV_t \ln 10}C_{ox} \tag{6}$$

Here D_{it} is the density of interface trap, which is relative to the energy level, C_{ox} is the capacitance of gate oxide, q is the charge of single electron, V_t is the thermal voltage and ΔS is the change of subthreshold slope.

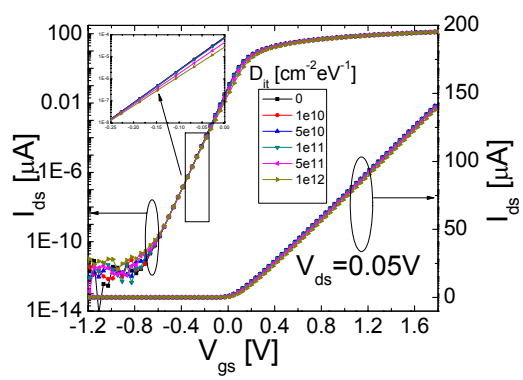

Fig. 4. Transfer characteristics curve with different interface trap density.

In the ISE-dessis, different interface traps are applied to the MOSFET and the simulation results are shown in Fig. 4. As it is shown in Fig.4, the subthreshold slope increases with the increase of D_{it}.

Based on the simulation result in Fig.4, the interface trap density extracted via Eq.(5) obtains a good agreement with D_{it} applied to the simulation, as shown in Fig. 5.

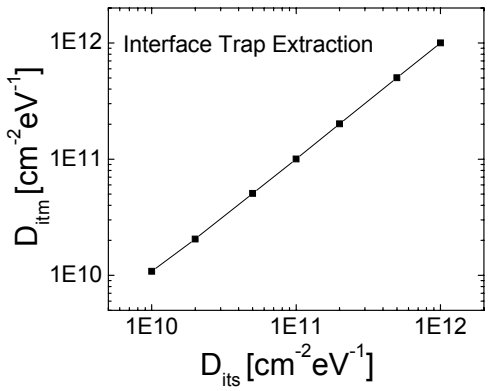

Fig. 5. Comparison between the extraction result and applied D_{it} based on the simulation result in Fig. 4. D_{itm} is the density of interface trap extracted from model, while D_{its} is the density of interface trap applied in the simulation

Through ISE simulation, it is proved that oxide trap makes the voltage shift, while interface trap changes the subthreshold slope.

3. DISCUSSION

Commonly, the oxide trap is extracted via the threshold voltage shift and the linear extrapolation method is perhaps the most popular method to extract threshold voltage. The threshold voltage is relative to the gate-voltage axis intercept of the transfer characteristics curve at its maximum first derivative point. The threshold voltage then equals to the gate-voltage axis intercept minus $V_{ds}/2$.

The threshold voltage shift (ΔV_{on}) is expressed in Equ(7)

$$\Delta V_{th} = -\frac{qN_{ot}}{C_{ox}} \tag{7}$$

Here N_{ot} is the density of oxide trap, C_{ox} is the capacitance of gate oxide, and q is the charge of single electron.

After the threshold voltage is extracted, ΔV_{th} is calculated for different applied N_{ot} densities. Thus, the gate oxide trap density is extracted via the method based on the threshold voltage shift.

In Fig. 7, a comparison of extraction deviation is made between the method applied in the subthreshold region and the method based on the threshold voltage shift.

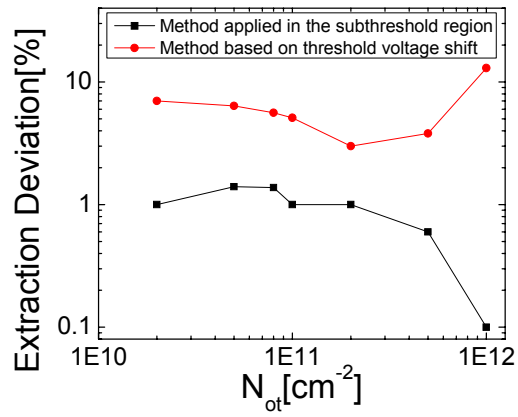

Fig.6. Comparison between two methods with gate length of 200nm.

Fig.6. demonstrates that the proposed method in this paper has an extraction deviation of about 2%, while the method based on the threshold voltage shift has an extraction deviation of about 10%.

With continuous scaling down, the method presents a good validity and accuracy of extracting gate oxide trap. The result is shown in Fig.7.

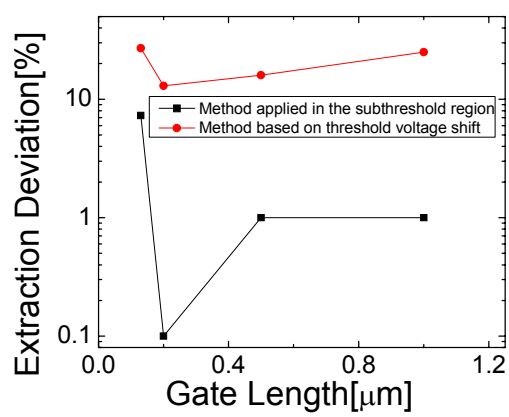

Fig.7. Comparison between two methods with different gate lengths.

4. CONCLUSION

This paper shows an accurate and effective method to extract and separate the gate interface and oxide trap. The method is verified by the ISE simulation. The simulation results demonstrate a good accuracy of our extraction method despite of the short channel effect and the degradation of mobility. Since gate interface trap and oxide trap is extracted via two independent factors, this

method is applicable in separating the gate interface and oxide trap.

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