Transconductance and Mobility Behaviors in UTB SOI MOSFETs with Standard and Thin BOX

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1. Abstract

In this paper, we analyze the effects of the front and back interfaces on the transport properties in undoped ultra-thin body (UTB) SOI MOSFETs with standard and ultra-thin buried oxides (BOX), using measurements of the transconductance, gate-to-channel capacitance and carrier mobility at various back gate biases.

2. Introduction

Fully-depleted (FD) SOI MOSFETs with undoped ultra-thin silicon bodies and metal/high-k gate dielectric stacks are needed for future nano-scale CMOS devices to satisfy the ITRS specifications [1]. The use of ultra-thin Si bodies provides an effective suppression of the short-channel effects (SCEs) without using channel doping [2], [3]. An additional improvement of the SCEs can be achieved by thinning the buried oxide layer [1], [4]. The transport properties of FD UTB SOI, depending on the quality of both SOI film interfaces, have been the subject of extensive studies in the recent years [5], [6]. In this paper, we present further investigations of the transport properties of undoped UTB SOI with standard (145-nm-thick) and ultra-thin (12.5-nm-thick) BOX, using an analysis of the transconductance, gate-to-channel capacitance and carrier mobility in long-channel MOSFETs at different back-gate biases.

3. Experimental Details

The devices were fabricated at CEA-LETI using UNIBOND (100) SOI wafers with 145-nm- and 12.5-nm-thick BOX. In the channel region, the Si body was thinned down to about 11 nm. Elevated source-drain structures were employed to reduce parasitic resistance. No channel doping was used. The gate stack consisted of ALD HfO_2 with EOT of 1.75 nm, and TiN gate electrode. The measured devices were n-channel MOSFETs with the channel length L=10 µm and the channel width W=10 µm. The carrier mobility was determined by split-CV, using measurements of the drain current (I_d) at a low drain voltage (V_d) and gate-to-channel capacitance (C_{gc}) versus the front gate voltage (V_{gf}) at various back gate voltages (V_{gb}) [5], [6].

4. Results and Discussion

Fig.1 shows $I_d(V_{gf})$-characteristics for various V_{gb} measured at V_d=50 mV for $t_{BOX=}$145 nm. One can see that in the case of UTB SOI device, it is very difficult to decorrelate the front and back channel conductions using the $I_d(V_{gf})$-characteristics. Indeed, as shown in the inset in Fig. 1, for high positive V_{gb}, only one pronounced peak is observed in the d^2I_d/dV_{gf}^2-curve corresponding to the formation of the inversion channel at the back interface, while the onset of front channel inversion is not clearly visible.

Shown in Fig. 2 are $g_m(V_{gf})$-curves for various V_{gb} in thick (full symbols) and thin (open symbols) BOX devices. $g_m(V_{gf})$-curves for positive V_{gb} feature two distinct humps related to the back and front channels. For $V_{gb} \leq 0$, only a single peak originating from the front channel is observed. The fact that the first peak in Fig. 2 related to the back channel is higher than the second peak associated with the front channel, suggests that the electron mobility at the back interface is higher than at the front interface. This is confirmed by $g_m(V_{gb})$-characteristics for various V_{gf} (Fig. 3).

Fig. 4 presents $C_{gc}(V_{gf})$-characteristics measured for the thick BOX device at various V_{gb}. The capacitance plateau observed at high positive V_{gb} is due to back inversion channel. This disappears at $V_{gb} \leq 0$, when only the front channel is activated [7]. Integrating the $C_{gc}(V_{gf})$-curves yields the inversion carrier density $N_{inv}(V_{gf}, V_{gb})$ [5], which is then used in the determination of the effective mobility (μ_{eff}). Besides, the derivative of the gate-to-channel capacitance (dC_{gc}/dV_{gf}) provides the values of V_{gf} at a given V_{gb} corresponding to the onset of inversion at the back and front interfaces, which is in essence identical to the second derivative of the drain current but offers much better resolution (inset in Fig. 4) because it is unaffected by the front channel/back channel mobility ratio. The arrow in Fig. 4 indicates V_{gf} at which the maximum transconductance is observed.

Fig. 5 shows μ_{eff} obtained by split-CV and plotted as a function of V_{gf} for various V_{gb}. It can be noted that μ_{eff} is nearly twice higher when controlled by the back interface (in a thick BOX device, this occurs at V_{gf}<0.4

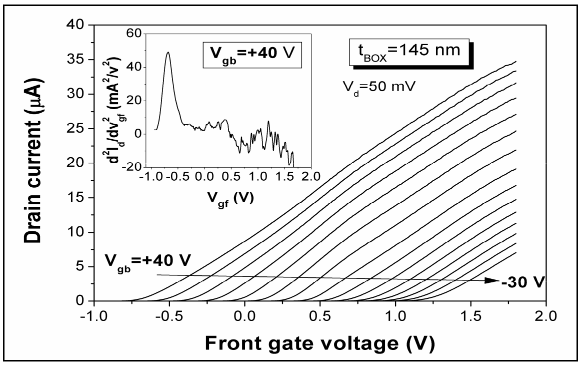

Fig. 1: *$I_d(V_{gf})$-characteristics measured in a thick BOX device at V_d=50 mV for various back gate biases varied from +40 V to -30 V with a 5 V step. Shown in the inset is the second derivative of the drain current for V_{gb}=+40 V.*

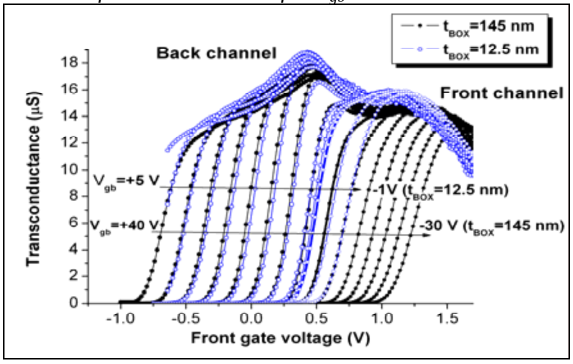

Fig. 2: *Transconductance vs. the front gate voltage for various back gate biases: full symbols – t_{BOX}=145 nm; open symbols – t_{BOX}=12.5 nm (V_d=50 mV, W/L=10 μm/10 μm).*

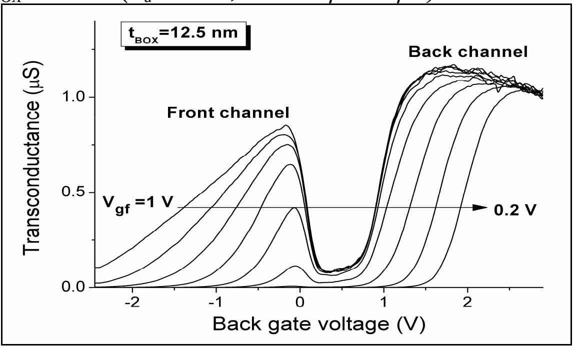

Fig. 3: *Transconductance of a thin BOX device as a function of the back gate voltage with front gate voltage as a parameter varied with 0.1 V step (V_d=10 mV).*

V for V_{gb}=+40V and +35 V), than when controlled by the front interface ($V_{gb}\leq0$). One can note a good agreement between behaviors of μ_{eff} in Fig. 4 and g_m in Fig. 2. The maximum μ_{eff} and g_m are observed when two inversion channels co-exist and the inversion charge centroid is located near the center of the film (~6 nm from the top). This suggests that in the vicinity of the maximums, the transconductance and mobility are enhanced by volume inversion. As follows from Figs. 2 and 5, in thin BOX devices, no degradation of g_m and μ_{eff} compared to thick BOX is observed. Another conclusion following from Fig. 5 is that, in UTB SOI MOSFETs with a significantly different front and back μ_{eff}, the averaged mobility at a given V_{gf} should be very sensitive to the variations in the BOX charge.

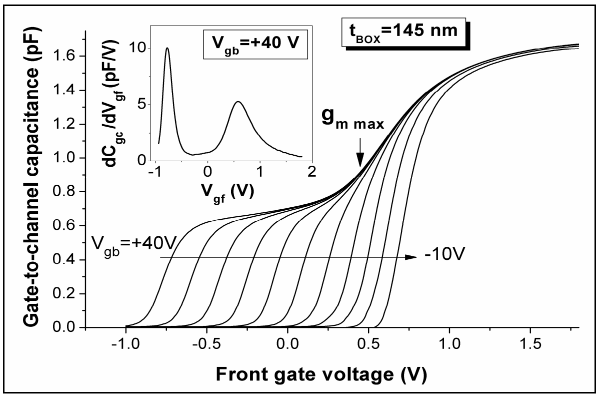

Fig. 4: *Gate-to-channel capacitance measured as a function of V_{gf} in a thick BOX device for various V_{gb} varied from +40 V to -10 V with a 5 V step (W/L=10 μm/10 μm, f=100 kHz).*

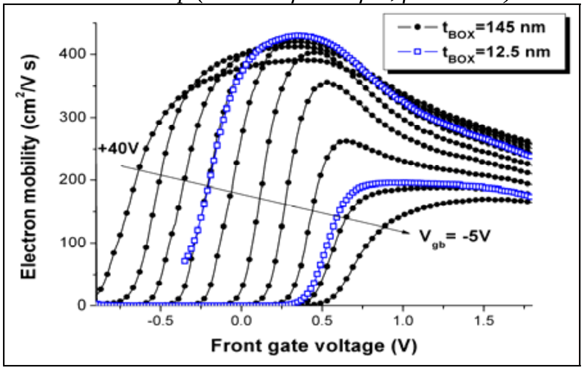

Fig. 5: *Effective electron mobility in the thick BOX device (full symbols) as a function of V_{gf} at various V_{gb}. For comparison open symbols show μ_{eff} in a thin BOX device at V_{gb}=0 V and V_{gb}=3V when $g_{m\ max}$ is achieved.*

5. Conclusions

The mobility at the back interface in the UTB SOI MOSFETs with high-k gate dielectric and both thick and thin BOX is found to be significantly (nearly twice) higher than that at the front interface, which is presumably due to different front (TiN/HfO$_2$) and back (Si/SiO$_2$) gate stacks. The maximum mobility in the studied undoped ultra-thin SOI devices is slightly enhanced by volume inversion. BOX thinning does not degrade μ_{eff}. The observed large scatter in μ_{eff} at zero substrate bias is likely related to scatter in the BOX charge, rather than to variations in the Si film thickness.

Acknowledgements

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