Mobility extraction in ultra thin, body buried oxide and fully depleted silicon-on-insulator MOSFET

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Abstract

In this paper, we extract the mobility of ultra-thin, body buried oxide and fully depleted silicon-on-insulator MOSFET, for different front and back-gate configurations. The mobility values are found by using the Capacitance - Gate Voltage and Current - Gate Voltage characteristics. In addition, the maximum electron mobility is calculated for both configurations: SiON/Si (front-gate) and SiO₂/Si (back-gate). Based on the mobility peak, it is determined that the electron transport can be improved by a factor of 1.6 for the front gate configuration. This improvement is explained by the back-channel activation. On the other hand, for the back-gate configuration the electron mobility is improved by a factor of 2.5. A second peak is observed in the electron mobility but cannot be appreciated, mainly because of the influence of an additional capacitance.

Keywords. UTBB-FD-MOSFET, silicon-on-insulator, mobility, front-gate configuration, back-gate configuration

Introduction

The silicon-on-insulator (SOI) technology presents interesting advantages with respect to the bulk silicon in terms of higher speed, lower power consumption, less parasitic effects and advanced scalability [1–4]. This technology has been explored for around 30 years and in the last 10 years, it has been implemented in commercial computer processors [5]. The SOI technology introduces some parameters that can be used for optimization of performance and scaling like the back-gate voltage (V_G2) and substrate doping [2–4]. As well, it has been shown that the short channel effects are reduced in ultra-thin SOI MOSFETs [2–4].

In fully depleted (FD) SOI MOSFETs, the back-gate voltage plays an important role in the control of the threshold voltage (V_TH) and in the behavior of the drain current (I_D). The strong interface coupling enables to enhance the drain current. The electron mobility is also

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Resumen

En el presente trabajo, se extrae la movilidad de dispositivos MOSFET de silicio en aislante, ultra delgados y agotados completamente, para las configuraciones de compuerta frontal y trasera. Los valores de movilidad fueron encontrados usando las características Capacitancia - Volaje de Compuerta y Corriente de Drenaje - Volaje de Compuerta. Adicionalmente, se calcula el máximo de movilidad de electrones para ambas configuraciones: SiON/Si (compuerta frontal) y SiO₂/Si (compuerta trasera). En base al pico de movilidad encontrado, se determina que el transporte de electrones puede ser mejorado por un factor 1.6 para la compuerta frontal. Esta mejora se explica por la activación de la compuerta trasera. Por otro lado, en la configuración de compuerta trasera la movilidad de electrones se mejora en un factor 2.5. Un segundo pico puede ser observado en la movilidad de electrones, sin poder ser apreciado con claridad y siendo originado por la presencia de una capacitancia adicional.

Palabras Clave. UTBB-FD-MOSFET, silicio en aislante, movilidad, configuración de compuerta frontal, configuración de compuerta trasera
The UTBB-FD-SOI-MOSFETs devices used during this work have a 10×10 μm² area. The front gate dielectric consists of 2.5nm SiON thickness, the body of 8nm of Si with doping of about 10¹⁵ cm⁻³ and the buried oxide consist of 10 nm of SiO₂ (Figure 1). The Front gate electrode is made of 5nm of TiN with poly-Si cap. The mobility extraction is carried out using the I-V and C-V characteristic method. For the C-V characteristic the Split C-V method was applied [6, 7]. First of all, the mobility of the front gate was extracted for different front gate biases (V_{FG}), in a range between 0V-5V (step of 0.1V). Once the source-to-drain current (I_{DS}) and the inversion capacitance C_{inv} were extracted, we assess the mobility by mean of the next expression [8]:

\[
\mu_{\text{eff}} = \frac{L}{V_{DS} \cdot Q_{\text{inv}} \cdot W \cdot I_{D}}
\]

Where \(L[\mu m]\) is the length and \(W[\mu m]\) is the width of the device, \(V_{DS}[V]\) is the drain to source voltage, \(Q_{\text{inv}}[C/cm²]\) is the inversion charge and \(I_{D}[A]\) is the drain current.

The effective electric field \(E_{\text{eff}}\) in SOI devices can be found using the next expression for the front-gate:

\[
E_{\text{eff}}^{FG} = \frac{1}{2} Q_{\text{inv}} \left( 1 + \frac{C_{P}}{C_{FG}} Q_{\text{inv}}^{BG} \right)
\]

Where \(E_{\text{eff}}^{FG}\) is the effective electric field for the front-gate, \(Q_{\text{inv}}^{BG}\) is the inversion charge in the back-gate, \(Q_{\text{inv}}^{FG}\) is the inversion charge in the back-gate, \(C_{FG}[F/cm²]\) is the front-gate capacitance and \(C_{P}\) is \(C_{FG} / C_{BG}\) (back-gate capacitance). Equation (2) is also used for computing the effective field in the back-gate, just changing the corresponding front-gate parameters and the back-gate parameters.

It is important to mention that the back-gate contact does not use a metallic electrode as the front gate but the p-type well of the Si substrate (below the burrier oxide, Figure 1). This produces extra gate capacitance capacitances that must be considered in the expressions as it will be discussed in great detail in the next section.

**Experimental Results**

**Front Gate-Configuration (SiON/Si interface)**

For all measurements done in this configuration, the voltage \(V_{G2}\) was varied in a range of 0.5V with 0.5V in every step. Figure 2 shows the C-V characteristic for the SiON/Si interface for different \(V_{G2}\). We can see that there are two rising regions in the curve: the first one is due to the effect of \(C_{Si}\) and \(C_{OX}\) (Figure 1) and the second one is the value of \(C_{OX}\) alone. We have found that \(C_{OX} = 1.6 \times 10^{-7} F/cm²\). Figure 3 shows the \(Q_{\text{inv}}\) vs. \(V_{G1}\) that is the integral of the C-V characteristic. The \(I_{D} - V_{G1}\) characteristic is shown in Figure 4. Figures 5 and 6 show the \(\mu_{\text{eff}}\) vs. \(Q_{\text{inv}}\) and \(\mu_{\text{eff}}\) vs. \(E_{\text{eff}}\), respectively.

The mobility peak is extracted and plotted in function of \(V_{G2}\) in Figure 7. We can see that the maximum peak of mobility occurs at \(V_{G2}=3V\) with \(\mu_{\text{eff}}=480 cm²/V.s\). This means that the back-gate contribution is able to increase the electron mobility in around 60%. The increase of the mobility peak can be explained by the activation of the back-channel which is consistent with [9]. Apparently, the back-channel is the only one activated, which will be confirmed in next configuration.

**Back Gate-Configuration (SiO₂/Si interface)**

Figure 8 shows the C-V characteristic for the back-gate configuration. Similarly, the first rising is due to the effect of \(C_{Si}\) and \(C_{BOX}\) (model in Figure 1). According to the device dimensions and the second rising of the C-V curve in Figure 8, we have: \(C_{Si}=1.3 \times 10^{-6} F/cm²\) and \(C_{BOX}=3.3 \times 10^{-7} F/cm²\). The value of the first rising is around \(C’=1.3 \times 10^{-7} F/cm²\), which cannot be explained by considering only \(C_{Si}\) and \(C_{BOX}\). At this point, we have the presence of an additional capacitance: \(C_{X}\) (Figure 1). By using the model presented in Figure 1, we obtain that \(C_{X}=2.6 \times 10^{-7} F/cm²\) and that the silicon substrate located below the SiO₂ dielectric (of about 10nm) has a thickness of 40 nm. Figures 9 and 10 show the curves: \(Q_{\text{inv}}\) vs. \(V_{G2}\) and \(I_{D}\) vs. \(V_{G2}\), which are used for the mobility extraction. The transconductance parameter \((G_{M})\) is plotted in Figure
Figure 2: Inversion capacitance ($C_{\text{inv}}$) vs. Front gate voltage ($V_{G1}$) for the front gate configuration. These parameters are directly extracted from the devices.

Figure 3: Inversion charge ($Q_{\text{inv}}$) vs. Front gate voltage ($V_{G1}$) for the front gate configuration. These curves are the result of the numerical integration of $C_{\text{inv}}$.

Figure 4: Drain current ($I_D$) vs. Front gate voltage ($V_{G1}$) for the front gate configuration. These parameters are directly extracted from the devices.
Figure 5: Mobility ($\mu_{\text{eff}}$) vs Inversion charge ($Q_{\text{inv}}$) for the front gate configuration. Equation (1) is used for the mobility computation.

Figure 6: Mobility ($\mu_{\text{eff}}$) vs Effective electric field ($E_{\text{eff}}$) for the front gate configuration. Equation (2) is used for the electric field computation.

Figure 7: Mobility Peak ($\max(\mu_{\text{eff}})$) vs Back gate voltage ($V_{G2}$) for the front gate configuration. Maximum electron transport occurs at $V_{G2}=3$V.
Figure 8: Inversion capacitance \( (C_{\text{inv}}) \) vs. back-gate voltage \( (V_{G2}) \) for the back-gate configuration. These parameters are directly extracted from the devices.

Figure 9: Inversion charge \( (Q_{\text{inv}}) \) vs. back-gate voltage \( (V_{G2}) \) for the back-gate configuration. These curves are the result of the numerical integration of \( C_{\text{inv}} \).

Figure 10: Drain current \( (I_D) \) vs. back-gate voltage \( (V_{G2}) \) for the back-gate configuration for the back-gate configuration.
Figure 11: Trans-conductance ($G_M$) vs. back-gate voltage ($V_{G2}$) for the back-gate configuration. Two peaks are evident for voltages $V_{G1}>0.5\text{V}$.

Figure 12: Mobility ($\mu_{\text{eff}}$) vs Inversion charge ($Q_{\text{inv}}$) for the back-gate configuration. Equation (1) is used for the mobility computation. A second peak can be observed for $V_{G1}>0.5\text{V}$.

11. We can see that there are two local maxima for the curves $V_{G1} \geq 0.6\text{V}$. The first peak is caused by the activation of the front gate and is lower than the second one.

Figures 12 and 13 show the curves $\mu_{\text{eff}}$ vs. $Q_{\text{inv}}$, $\mu_{\text{eff}}$ vs. $E_{\text{eff}}$ for different $V_{G1}$. For curves $V_{G1} \geq 0.6\text{V}$, we can see that there are two local maxima of mobility, as we obtained for $G_M$. In this case, the first peak is higher than the second one which is consistent with the low capacitive value of $C_X$. The nature of this peak is not clear and a further study is needed to determine its role. However, it occurs only for negative back-gate bias, corresponding to strongly decreasing front-gate mobility; which is our main interest in this work.

The peak of mobility vs. $V_{G1}$ is shown in Figure 14. If we eliminate the first peak of mobility for curves $V_{G1} \geq 0.6\text{V}$, we can see that the mobility stabilizes at $V_{G1}=0.4\text{V}$ with $\mu_{\text{eff}}=450 \text{ cm}^2/\text{V.s}$. Again, the increase of the mobility peak with respect to $V_{G1}$ is because of the activation of the front-channel. The contribution of the front-channel is able to increase the back-gate mobility in around 150%. The maximum values of mobility obtained in both configurations are very similar (6.66% of discrepancy) which confirms that the back-channel is the only one activated in the front-gate configuration consistent with [9].

Conclusions

The mobility parameter was extracted successfully in UTBB-FD-SOI-MOSFETs devices for the front and back-gate configurations. The maximum values of electron transport were obtained for $V_{G2}=3\text{V}$ for the front gate configuration. A 60% of mobility increase can be obtained by the contribution of the back-gate, which increases the device performance considerably. In the case of the back-gate configuration, the tendency of the re-
Figure 13: Mobility ($\mu_{\text{eff}}$) vs Effective electric field ($E_{\text{eff}}$) for the back-gate configuration. Equation (2) is used for the electric field computation, with the respective changes.

Figure 14: Mobility Peak ($\max(\mu_{\text{eff}})$) vs. front-gate voltage ($V_{G1}$) for the back-gate configuration. From $V_{G1} = 0.6 V$ two mobility peaks can be observed. The first peak rises faster than the second, this is related with the first trans-conductance peak.

Results was different: two peaks were obtained for the curves of trans-conductance and mobility. The appearance of the first peaks, in both curves, is related with the activation of the front gate.

The presence of an additional capacitive component, $C_x$, causes a large increment of the first mobility peaks for the curves $V_{G1} \geq 0.6 V$, but this peak is related to the negative $V_{G2}$ bias, where the front-gate mobility is getting decreased. Note that the maximum values of mobility stabilize at $V_{G1} = 0.4 V$. In the back-gate configuration, the contribution of the front-gate bias is able to increase the back-gate mobility in 150%. These experiments confirm that back-channel is the only one activated when the front channel reach its maximum. However, for larger $V_{G2}$, the mobility decreases in the front-gate configuration. In further experiments, it is planned to study the transport for high-$k$ devices and understand what is happening for large $V_{G2}$.

Acknowledgments

The authors would like to thank Imec (Belgium) for providing the studied UTBB-FD-SOI-MOSFETs samples.

References


