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To cite this version:


HAL Id: jpa-00254226

https://hal.archives-ouvertes.fr/jpa-00254226

Submitted on 1 Jan 1996

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Mobility Degradation Influence on the SOI MOSFET Channel Length Extraction at 77 K

A.S. Nicolett*, J.A. Martino, E. Simoen** and C. Claeys**

Laboratório de Sistemas Integráveis, Universidade de São Paulo, Brazil
* Faculdade de Tecnologia de São Paulo, Brazil
** IMEC, Kapeldreef 75, 3001 Leuven, Belgium

Abstract: This work studies the influence of mobility degradation on the effective channel length \( L_{\text{eff}} \) \( (L_{\text{eff}} = L_m - \Delta L) \) extraction in submicron fully depleted SOI MOSFETs at 77 K. Second-order effects can cause mobility degradation, mainly at 77 K, and if standard techniques have been used, negative values of \( \Delta L \) can be obtained. It will be shown that this result can be caused by a length-dependent mobility degradation factor.

1. INTRODUCTION

Effective channel length \( L_{\text{eff}} \) and effective mobility \( \mu_{\text{eff}} \) are important parameters for process control and device performance. Several techniques \([1 - 4]\) have already been developed to extract \( L_{\text{eff}} \) and typically this parameter is calculated from I_dV_{gs} data on transistors with different channel lengths \( L_m \) \( (L\text{-array}) \). \( L_{\text{eff}} \) \( (L_m - \Delta L) \) is extracted with electrical techniques and reflects an electrical dimension, not necessarily a physical dimension \([2]\). The channel ends where the gate-induced carrier density equals the doping density in the LDD regions. This implies that an increment of the charge in the channel by raising the gate overdrive voltage \( (V_{gs} - V_{th}) \) will result in an extension of the channel into the LDD regions \([2]\).

The different extraction techniques assume that the mobility degradation factor is constant for all \( L\text{-array} \) transistors. However, when the dimensions of the devices are scaled down, second-order effects appear, such as increase of the source-drain resistance \([5]\), and a variation of the threshold voltage due to short channel \([6]\) and hot electron effects \([7]\). These second-order effects can cause mobility degradation, especially at 77 K \([8]\). Consequently, using the standard electrical extraction techniques, negative values for \( \Delta L \) can be obtained. In this work the effect of mobility degradation on the \( L_{\text{eff}} \) extraction in submicron fully depleted SOI nMOSFETs at 77 K is studied both experimentally and by simulation.

2. EXPERIMENTAL DETAILS AND RESULTS

The SOI nMOSFETs studied were fabricated with drawn channel width \( W_m \) of 20 \( \mu \)m and different drawn channel lengths \( L_m \) of 0.7, 0.8, 0.9, 1.0, 1.2, 1.5, 2.0 \( \mu \)m in a 0.5 \( \mu \)m SOI Technology on SIMOX substrates. The front gate oxide thickness \( t_{\text{ox}} \) is 15 nm, the buried oxide thickness \( t_{\text{box}} \) is 390 nm, and the silicon film thickness \( t_{\text{si}} \) is 100 nm. The I_dV_{gs} curves were recorded with \( V_{ds} = 0.1 \) V, \( V_{gs} \) ranging from -1 to +3 V (steps of 0.01 V), back gate voltage \( V_{gb} = -5 \) V and temperature at 77 K. The I_dV_{gs} curves (figure-1) were measured by using an HP 4145A parameter analyzer, while the threshold voltage...
$V_{th}$ was determined for each transistor by the Linear Extrapolation Method. The effective channel length $L_{\text{eff}}$ ($L_m - \Delta L$) was obtained from $I_{ds}$-$V_{gs}$ curves by using the technique proposed in [2]. Figure-2 shows the corresponding negative value of $\Delta L$ obtained.

![Figure-1: Curves $I_{ds}$-$V_{gs}$ for L-array at 77 K (experimental).](image1)

![Figure-2: $\Delta L$ of fully depleted SOI nMOSFETs (experimental) at 77 K as a function of the gate overdrive voltage.](image2)
3. SIMULATION RESULTS

In order to study the influence of the mobility degradation on the $\Delta L$ extraction, MEDICI [9] simulations are performed of fully depleted SOI nMOSFETs with drawn channel lengths $L_m$ of 0.8, 1.0, 1.2, 1.4 $\mu$m, $W_m = 20 \mu$m, $t_{FOX} = 15$ nm, $t_{BOX} = 390$ nm, $t_{SI} = 100$ nm, $V_{DS} = 0.1$ V, and $V_{GS}$ ranging from 0.1 to 2.5 V (steps of 0.01 V). MEDICI includes a model for the perpendicular electric field reduction of effective mobility given by equation (1), where $GSURFN$ is the surface degradation factor, $E_\perp$ is the component of perpendicular electric field, $\mu_o$ is the low field mobility (concentration and temperature dependent) and $ECN.MU$ is the critical electrical field.

$$\mu_{eff} = GSURFN \frac{\mu_o}{\sqrt{1 + \frac{E_\perp}{ECN.MU}}}$$ (1)

As it is known that the surface mobility degradation factor decreases for decreasing gate lengths [10], mainly for low temperatures [8], two simulations were performed: in the first, the surface mobility degradation factor $GSURFN$ was maintained constant ($GSURFN = 0.75$) for all transistors of the $L$-array; in the second, the surface mobility degradation factor was varied for each transistor from $GSURFN$ equal 1.0 (longest) to 0.5 (shortest), i.e., for $L_m$ of 0.8, 1.0, 1.2, 1.4 $\mu$m, the values of the $GSURFN$ were 0.5, 0.75, 0.9, 1.0, respectively. Figure-3 shows the results of $\Delta L$ ($\Delta L = L_m - L_{eff}$) as a function of the gate overdrive voltage ($V_{GS} - V_{TH}$). This figure shows that if a non constant surface mobility degradation factor is used, negative $\Delta L$ values are obtained and the extraction procedure can not be used.

Figure-3: $\Delta L$ of fully depleted SOI nMOSFETs (simulation) at 77 K as a function of the gate overdrive voltage and $GSURFN$. 

$T = 77$ K - SOI nMOSFETs

- Constant $GSURFN$
- Different $GSURFN$
4. DISCUSSION

The experimental surface mobility degradation factor can be estimated by comparison of the $I_{ds}$ curves of the L-array, equation (2), considering the oxide capacitance $C_{ox}$ and the effective drawn channel width $W_{eff}$ as constant parameters for all transistors of the L-array, negligible threshold voltage changes and a low series resistance. The estimated surface mobility degradation factor $(GSURFN)_{est}$ can be obtained by relation (3), using the longest transistors as a reference, i.e., $(GSURFN)_{ref} = 1$, and $L_{eff} \approx L_m$.

\[
\frac{(I_{ds})_{ref}}{(I_{ds})_{est}} = \frac{(\mu_{eff})_{ref}}{(\mu_{eff})_{est}} \frac{(L_{eff})_{est}}{(L_{eff})_{ref}}
\]

\[
(GSURFN)_{est} = \frac{(I_{ds})_{est}}{(I_{ds})_{ref}} \frac{(GSURFN)_{ref}}{(L_{m})_{est}} \frac{(L_{m})_{est}}{(L_{m})_{ref}}
\]

Figure-4 shows the values of $(GSURFN)_{est}$ for transistors of the L-array of figure-1, and it can be seen that the values of the estimated surface mobility degradation factor are not constant. This confirms the hypothesis suggested by simulations.

![Figure-4: $(GSURFN)_{est}$ (experimental) as a function of the gate voltage.](image)
5. CONCLUSION

It was demonstrated both by simulations and experimentally that negative $\Delta L$ values can be obtained if the mobility degradation factor changes into each transistor of a same L-array. In this case non of the $\Delta L$ extraction methods can be applied, and a new extraction technique must be developed.

References: