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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_{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 ΔL 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_{eff} and effective mobility μ_{eff} are important parameters for process control and device performance. Several techniques [1 - 4] have already been developed to extract L_{eff} and typically this parameter is calculated from $I_{\text{ds}}-V_{\text{gs}}$ data on transistors with different channel lengths L_m (L-array). L_{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 ($V_{\text{gs}} - V_{\text{th}}$) 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-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 ΔL can be obtained. In this work the effect of mobility degradation on the L_{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 μm and different drawn channel lengths L_m of 0.7, 0.8, 0.9, 1.0, 1.2, 1.5, 2.0 μm in a 0.5 μm SOI Technology on SIMOX substrates. The front gate oxide thickness t_{fox} is 15 nm, the buried oxide thickness t_{box} is 390 nm, and the silicon film thickness t_{si} is 100 nm. The $I_{\text{ds}}-V_{\text{gs}}$ curves were recorded with $V_{\text{ds}} = 0.1$ V, V_{gs} ranging from -1 to +3 V (steps of 0.01 V), back gate voltage $V_{\text{gb}} = -5$ V and temperature at 77 K. The $I_{\text{ds}}-V_{\text{gs}}$ curves (figure-1) were measured by using an HP 4145B parameter analyzer, while the threshold voltage

V_{th} was determined for each transistor by the Linear Extrapolation Method. The effective channel length L_{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 ΔL obtained.

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

Figure-2: ΔL of fully depleted SOI nMOSFETs (experimental) at 77 K as a function of the gate overdrive voltage.

3. SIMULATION RESULTS

In order to study the influence of the mobility degradation on the ΔL 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 μm , $W_m = 20 \mu\text{m}$, $t_{\text{fox}} = 15 \text{ nm}$, $t_{\text{box}} = 390 \text{ nm}$, $t_{\text{si}} = 100 \text{ nm}$, $V_{\text{ds}} = 0.1 \text{ V}$, 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, μ_0 is the low field mobility (concentration and temperature dependent) and ECN.MU is the critical electrical field.

$$\mu_{\text{eff}} = \text{GSURFN} \frac{\mu_0}{\sqrt{1 + \frac{E_{\perp}}{\text{ECN.MU}}}} \quad (1)$$

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 μm , the values of the GSURFN were 0.5, 0.75, 0.9, 1.0, respectively. Figure-3 shows the results of ΔL ($\Delta L = L_m - L_{\text{eff}}$) as a function of the gate overdrive voltage ($V_{\text{gs}} - V_{\text{th}}$). This figure shows that if a non constant surface mobility degradation factor is used, negative ΔL values are obtained and the extraction procedure can not be used.

Figure-3: ΔL of fully depleted SOI nMOSFETs (simulation) at 77 K as a function of the gate overdrive voltage and 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 $L_{eff} \approx L_m$.

$$\frac{(I_{ds})_{ref}}{(I_{ds})_{est}} = \frac{(\mu_{eff})_{ref} (L_{eff})_{est}}{(\mu_{eff})_{est} (L_{eff})_{ref}} \quad (2)$$

$$(GSURFN)_{est} = \frac{(I_{ds})_{est}}{(I_{ds})_{ref}} \frac{(GSURFN)_{ref} (L_m)_{est}}{(L_m)_{ref}} \quad (3)$$

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.

5. CONCLUSION

It was demonstrated both by simulations and experimentally that negative ΔL values can be obtained if the mobility degradation factor changes into each transistor of a same L-array. In this case none of the ΔL extraction methods can be applied, and a new extraction technique must be developed.

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