Effective Channel Length Extraction of MOS Transistors with Halo/Pocket Implants

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Abstract— The shift-and-Ratio method has been considered as one of the most accurate and consistent techniques for extracting the effective channel-length of the MOS transistors. The use of original shift-and-ratio method for $L_{eff}$ extraction of MOS transistors with halo/pocket implants results in systematic errors for $L_{eff}$. In this paper a modification of the original method has been proposed and tested by simulation. The values of $L_{eff}$ generated by this method are more reasonable than the original shift-and-ratio method.

Keywords: Effective channel length, halo/pocket implant, parameter extraction, shift-and-ratio method
I. INTRODUCTION

The effective channel length of MOSFETs is an important parameter for both process monitoring and device design. A number of methods have been previously proposed for the measurement of this parameter [1]. These methods usually use the $I_{DS}-V_{GS}$ curves at low drain bias with $V_{GS}$ above the threshold voltage. Recently, Taur et al. [2],[3] presented an improved method called "Shift-and-Ratio" which have been proved useful for cases where no halo/pocket implants are used. However, scaling urges the use of halo/pocket implants in modern MOS transistors. Halo implants are used both to reduce drain induced barrier lowering (DIBL), and the possibility of punch-through breakdown [4],[5]. One of the assumptions made in the shift-and-ratio method is that the mobility for the short channel devices is equal to that of the large channel (reference) transistors. This, results in an unrealistic value for the extracted channel length in deep submicron transistors, particularly when a high dose of halo/pocket implant is used [6]. Eng. et al. [7] proposed using a gate voltage close to the threshold voltage. They thus assumed that the carrier mobility of the short channel transistors is equal to that of the long channel transistors. Note that, although this method eliminates the mobility degradation due to the vertical electric field, the problem regarding to mobility degradation due to the ionized impurity concentration is still remained unsolved. Moreover, the accuracy of the shift-and-ratio method becomes questionable in the low-$V_{GS}$ regime. This extraction technique is applied on a two-dimensional (2-D) device simulation data and the results have been compared by the original shift-and-ratio method.

II. SHIFT-AND-RATIO METHOD

Shift-and-ratio method is based on the channel resistance concept. It starts with a general relation of the form:

$$R_{sd}'(V_{GS}) = R_{sd} + L_{eff}' f(V_{GS} - V_t')$$  \hspace{1cm} (1)

Where, $f$ is a general function of gate overdrive voltage and the superscript $i$ denotes the $i$th device with an unknown effective channel length. The key assumption behind (1) is that the effective mobility is a common function of gate overdrive voltage for all measured devices. The problem is to find $R_{sd}$, $L_{eff}$, and $V_t$ in (1) from the measured data of $R_{sd} (V_{GS})$. The shift-and-ratio method simplifies the procedure by differentiating (1) and neglecting the variation of $R_{sd}$ by $V_{GS}$.

$$S'(V_{GS}) = \frac{dR_{sd}'}{dV_{GS}} = L_{eff}' \frac{df(V_{GS} - V_t')}{dV_{GS}}$$  \hspace{1cm} (2)

Here, $df/dV_{GS}$ is also a general function of gate overdrive voltage. Shift-and-ratio method is usually done with two devices: one long channel and one short channel. Fig. 1 shows an example of $S$-function of two devices, $S_L$ for $L_{mask}=10\mu m$, and $S_i$ for $L_{mask}=0.18\mu m$.

It would have been easy if $V_t' = V_t$, in which case $S'$ and $S$ were identical function of $V_{GS}$ and $L_{eff}'$ is simply solved from the ratio $S'/S$. In general, however, $V_t' \neq V_t$, and the two $S$-function must be shifted with respect to each other before the ratio is taken. The purpose here is to find the $\delta$ in the following relation:

$$r(\delta, V_{GS}) = \frac{S'(V_{GS})}{S(V_{GS} - \delta)}$$  \hspace{1cm} (3)

so that, the ratio $r$ becomes a constant, independent expression of $V_{GS}$. This procedure can be automated by calculating the average $r$ and the
Fig. 2. Variance (solid dot) versus gate voltage shift $\delta$. Data are taken from the device example in Fig. 1.

The mean square deviation of $r$ from its average value [3]:

$$\langle r^2 \rangle = \frac{\int r(\delta, V_{GS}) dV_{GS}}{\int dV_{GS}}$$

(4)

and,

$$\langle \sigma^2 \rangle = \langle r^2 \rangle - \langle r \rangle^2$$

(5)

as a function of $\delta$. In (4) $\Delta V_{GS}$ is a selected range of gate voltage. The gate voltage range in shift-and-ratio method is very critical. As mentioned in [3] if we choose starting point of this range near the subthreshold region where the current is controlled by diffusion over a potential barrier the extracted effective channel length becomes overestimated. So it is important to choose a gate voltage range in which the transistors are in linear region. Fig. 2 plots the example where the variance versus $\delta$ curve exhibits a sharp minimum at the point of best match [2], [3].

III. THEORY

From section II it is clear that the effective channel-length can only be extracted properly if the effective mobility of the reference device, $\mu^R(V_{GS})$, and the one for the short channel device, $\mu^S(V_{GS} - \delta)$, are identical. As explained in section I, this is not the case for the MOS transistor with halo/pocket implants [5]. In these devices the effective channel doping concentration is a function of channel length.

Fig. 3 shows a halo/pocket implanted transistor and its doping concentration near the oxide-substrate interface.

Two important processes that can cause degradation of mobility in MOS transistors are phonon scattering and Coulombic scattering. Obviously at room temperature, the effective channel mobility of the short channel transistor is lower than that of its equivalent long channel device due to its greater Coulombic scattering. By increasing the temperature for the long channel transistor its mobility decreases due to higher phonon scattering. Thus there must exist a temperature at which low-field mobility of the short channel device becomes equal to that of its equivalent long channel transistor. The key point of our proposed method is that we exactly adjust the low-field mobility factor so that the mobility of long channel transistor becomes equal to that of the short channel device.

For a halo/pocket implanted MOSFET the dependence of the $f$ function in equation (1) upon the mobility must be considered. So we can write:

$$R_{tot}(V_{GS}) = R_{id} + L_{eff} f(V_{GS} - V_i, \mu)$$

(6)

since,

$$\mu = \mu(V_{GS} - V_i, \mu_0)$$

(7)

we can rewrite (6) as:

$$R_{tot}(V_{GS}) = R_{id} + \frac{L_{eff} g(V_{GS} - V_i)}{\mu_0}$$

(8)

the shift-and-ratio method results in:
\[
\frac{S^L}{S^i} = \frac{L^L_{\text{eff}}}{L^i_{\text{eff}}} \frac{d\theta(\mu)(T^i)}{d\theta} \frac{d\theta(V_{GS})}{\theta(V_{GS}) - \theta}
\]

(9)

Now, assume that there exists a temperature \(T_S\) at which the \(\mu_0'\) at \(T^i = 300K = \mu_0^L(T_S)\). We have proposed an iteration method through which the correct temperature \(T_S\) can be found. The procedure is as follows:

1. Find the \(I_{DS}-V_{GS}\) characteristics for the long channel transistor at a temperature greater than room temperature.
2. Find \(L_{\text{eff}}\) using the original shift-and-ratio method.
3. Since \(L_{\text{eff}}\) is known from step 2, determine the low-field mobility ratio \(\mu_0^L / \mu_0^i\) using \(I_{DS}-V_{GS}\) characteristics.
4. If this ratio is different from unity, repeat steps 1 through 3.

IV. SIMULATION AND RESULTS

In order to test this method a 2-D device simulation [9] has been performed with quasi-ideal “box-like” profiles as illustrated in Fig. 3. Fig. 4 shows the extracted \(L_{\text{eff}}\) for NMOS transistors using the original shift-and-ratio method and our modified method for a 0.18\(\mu\)m CMOS technology. From Fig. 4 it is apparent that the values of \(L_{\text{eff}}\) generated by our method are more reasonable than the ones found by the original shift-and-ratio method. Moreover resulted \(T_S\) values are well within the range that can be experimented.

V. DISCUSSION

As explained above, in the large channel devices mobility degrades due to phonon scattering, while for the short channel transistor, it originates from the Columbic scattering. However, as long as the final mobility curves are identical, we are not interested in the different scattering mechanisms involved.

VI. CONCLUSION

While the original shift-and-ratio method overestimates \(L_{\text{eff}}\), our improved method gives more reasonable values for \(L_{\text{eff}}\). The problem of the dependence of the channel effective mobility upon channel length which cause inaccuracy in the results obtained from original shift-and-ratio method is alleviated by doing the measurement for the short channel transistor near room temperature, while doing similar measurement for the long channel transistor at a higher temperature as specified above.

To implement this new method we just need a set of measured data from a long channel transistor at different temperatures in a particular technology. So this improved method can be easily implemented into automatic wafer level electrical testing systems.

VII. REFERENCES

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