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A Self-Consistent Effective-Channel-Length/External-Resistance Extraction Method for Small-Geometry MOSFET's

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A novel method for self-consistently extracting effective channel length (L_{eff}) and external resistance (R_{ext}) has been proposed. In the method, L_{eff} is defined as the length of the region where local V_{th} forms a plateau and is independent of the gate voltage (V_g), while R_{ext} can be V_g-dependent. The definition is device-physically meaningful and practically useful making circuit models simple. The method was evaluated by a 2D device simulation and by an experiment utilizing devices of a 0.4 μm CMOS technology. A resolution as high as 0.003 μm was demonstrated.

1. INTRODUCTION

Effective channel length (L_{eff}) and external series resistance (R_{ext}) are key parameters in MOSFET's. So-called resistance method works well when source/drain diffusions are abrupt and heavily doped. The method assumes that the resistance in channel region is modulated by the gate voltage while R_{ext} is kept constant. However, as device dimensions scale down to submicron and source/drain diffusions become graded and/or lightly doped, the assumption is no longer valid and therefore the usefulness of the resistance method becomes degraded. To date a lot of works to solve the problem have been carried out and several kinds of modifications have been proposed[1]. In spite of these efforts, however, the essential problem that R_{ext} is assumed to be V_g-independent has not been well solved yet; the assumption is included, at least partly, in every previously proposed modification. The assumption gives rise to an inconsistency in extraction schemes.

In this paper, a self-consistent method is proposed which has a substantially different basis of extraction scheme. By the method, V_g-independent L_{eff} and V_g-dependent R_{ext} are extracted consistently.

2. THE NEW METHOD

The local threshold voltage, V_{th}, of a MOSFET is a function of position as schematically shown in Fig.1. It has a plateau. The magnitude of V_{th} for the plateau is regarded as the device threshold voltage, $\widetilde{V}_{th}$.

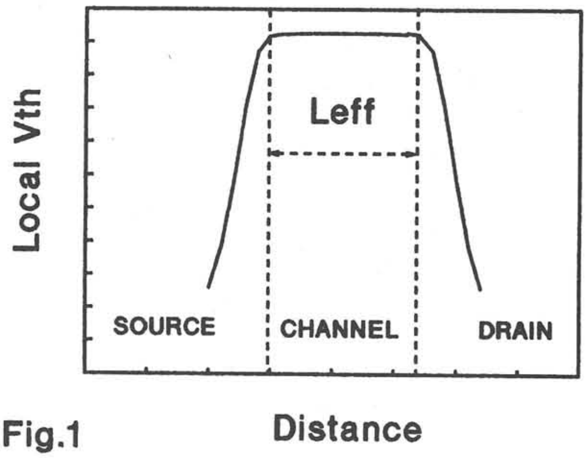

Fig.1

Schematical illustration of local Vth vs distance along the channel.

We define "channel" as the plateau region and call the outside regions external region. The sheet resistivity of the channel shows a steep increase as V_g comes down from a high value through the $\widetilde{V}_{th}$ (this steep increase is referred to as subthreshold behavior(SB)), while that of the external region dose not at the $\widetilde{V}_{th}$. The present method makes use of this difference to discriminate the external region from the channel region.

Now we consider two MOSFET's with different gate lengths. We call the longer one device 1 and the shorter one device 2 hereafter. For simplicity, we deal with the case where only the device 2 has a threshold voltage roll-off due to the short-channel effect.

Measured source-to-drain resistance for the device 1, R_1, and that for the device 2, R_2, are expressed as

$$R_1 = (L_1 - \Delta L)\rho_1 + R_{ext} \qquad (1)$$

$$R_2 = (L_2 - \Delta L)\rho_2 + R_{ext} \qquad (2)$$

where L is mask channel length, $L - \Delta L = L_{eff}$ is the effective channel length that is defined above (Fig.1), and ρ is channel resistance per unit length, which is a function of V_g. In general $\rho_1 \neq \rho_2$ because $\widetilde{V}_{th1} \neq \widetilde{V}_{th2}$.

If $\rho_1 = \rho_2$ (in fact, this condition is satisfied when a proper substrate bias voltage, V_{sub}, is applied to the device 2), then we get, from Eqs.1 and 2,

$$R_{ext} = \frac{(L_2 - \Delta L)R_1 - (L_1 - \Delta L)R_2}{L_2 - L_1}. \qquad (3)$$

As R_{ext} has no SB, the RHS of Eq.3 has no SB; the SB's of R_1 and R_2 are canceled out.

Now we consider how the RHS of Eq.3 behaves if ΔL is not correct or $\rho_1 \neq \rho_2$. We use the symbol $\widehat{R}_{ext}$ for the RHS of Eq.3 with an incorrect magnitude for ΔL or ρ_2 which dose not equal to ρ_1. After a simple algebraic treatment, we get

$$\widehat{R}_{ext} = R_{ext} + \frac{\widehat{L}_{eff1}\widehat{L}_{eff2}}{L_2 - L_1}(\rho_1 - \rho_2) - (\Delta\widehat{L} - \Delta L)\frac{\widehat{L}_{eff1}\rho_1 - \widehat{L}_{eff2}\rho_2}{L_2 - L_1}, \qquad (4)$$

where $\Delta\widehat{L}$ represents an incorrect magnitude for ΔL and $\widehat{L}_{eff} - L_{eff} = -(\Delta\widehat{L} - \Delta L)$. It is derived from Eq.4 that the SB's of ρ_1 and ρ_2 are not canceled out if $\Delta\widehat{L} \neq \Delta L$ or $\rho_1 \neq \rho_2$.

It is shown by the above that the magnitude for ΔL and that for V_{sub} that give a SB-free R_{ext}, are the correct magnitudes to be found. Now, our problem becomes how to find them. We use an error-and-trial method as shown in Fig.2. In practice, $\widehat{R}_{ext}$ closest to a linear function is regarded as of no SB. To perform this method, we measure, as a function of V_g, R_1 for $V_{sub} = 0$ and R_2 as a parameter.

3. DISCUSSION

We evaluated the new method by an experiment and a device simulation. The devices used are 0.4 μm- and 1.8 μm-gate length pMOSFET's with an LDD structure fabricated by a 0.4 μm CMOS technology. A V_{ds} of 0.05 V was applied for all R measurements.

An example of pre-convergence $\widehat{R}_{ext}(V_g)$'s as well as $R_{ext}(V_g)$ for the measured data is shown in Fig.3, demonstrating the high sensitivity of $\widehat{R}_{ext}(V_g)$ on $\Delta\widehat{L}$ variation and on $\widehat{V}_{sub}$ variation. A resolution in ΔL as high as 0.003 μm is archived in this case.

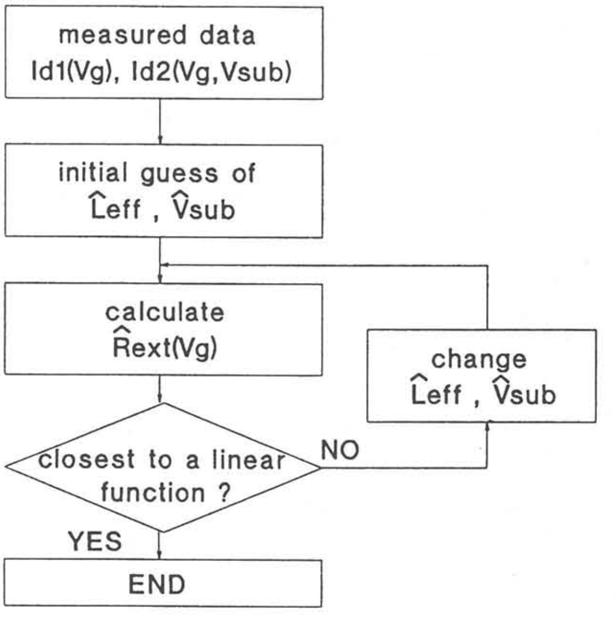

Fig.1 Scheme of the new method .

Fig.4 shows an impurity concentration under the gate oxide and the corresponding L_{eff} which is extracted by the new method from the R data calculated by MEDICI, 2D device simulator. The L_{eff} corresponds, within the accuracy of this simulation, to the region where the impurity concentration forms a plateau. In general, the plateau of the local V_{th} dose not precisely coincide with the plateau of the impurity profile, if the two-dimensional(2D) effect is taken into account. Detailed investigation seems to be required to address this issue. However, the fact that the extracted L_{eff} agrees with the plateau of the impurity profile, may suggest that the local V_{th} corresponds to the impurity profile even in such a short-channel device as investigated here.

In the above demonstration, $\widehat{R}_{ext}$ closest to a linear function is selected as of no SB. This, however, comes just from convenience. There seem to be more reasonable criteria which better reflect the characteristics of the external region.

The present method assumes that R_{ext} does not depend on V_{sub}. For practical devices, the dependence of V_{sub} on R_{ext} is not thought to be significant.

Finally, a comparison of the new method with the conventional methods is given in Table 1. Being different from the conventional methods, the new method has a complete consistency between the assumption made and the extracted parameters. The V_g-independent L_{eff} seems reasonable from device physics point of view and should make device modeling simple.

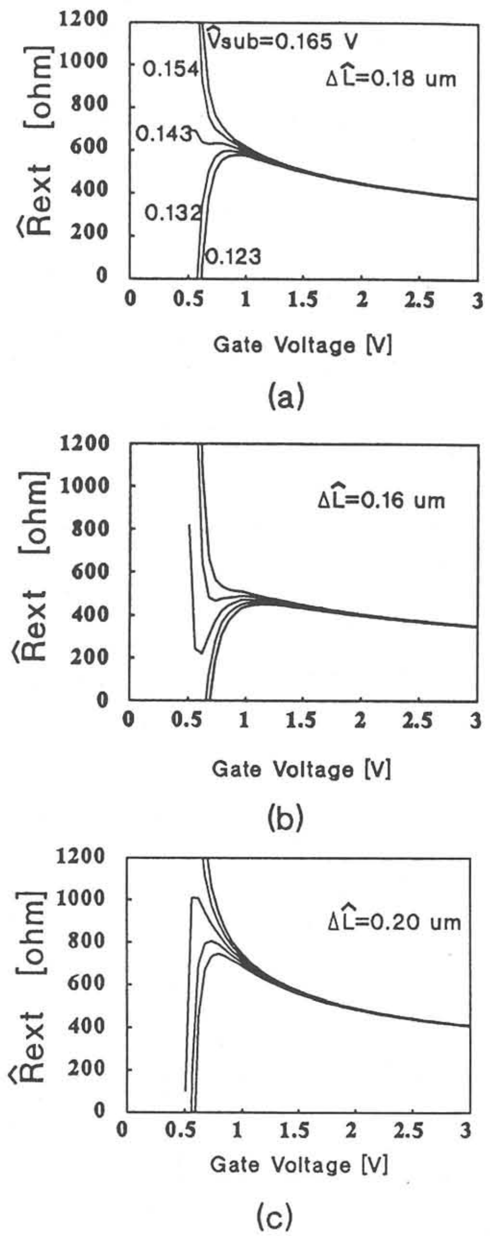

Fig.3 Plots of $\hat{R}$ext vs Vg with $\hat{V}$sub and $\Delta\hat{L}$ as parameters. The set of ΔL=0.18um and $\hat{V}$sub=0.143 V shown in (a) gives the $\hat{R}$ext closest to a linear function. Therefore this $\hat{R}$ext is the solution.

TABLE I

Comparison between new method and conventional method.

DEVICE TYPE	EXTRACTION METHOD	ASSUMPTION	PARAMETERS EXTRACTED Leff	Rext	PURPOSE DEVICE MODELING	PROCESS CONTROL	PHYSICAL MEANING
SD	conv	Rext=const (valid)	const	const	good	good	clear
LDD GDD	conv	Rext=const (not valid)	Leff(Vg)	Rext(Vg)	complex	inadequate	not clear
LDD GDD	new	Leff=const Rext arbitrary	const	Rext(Vg)	less complex	good	clear

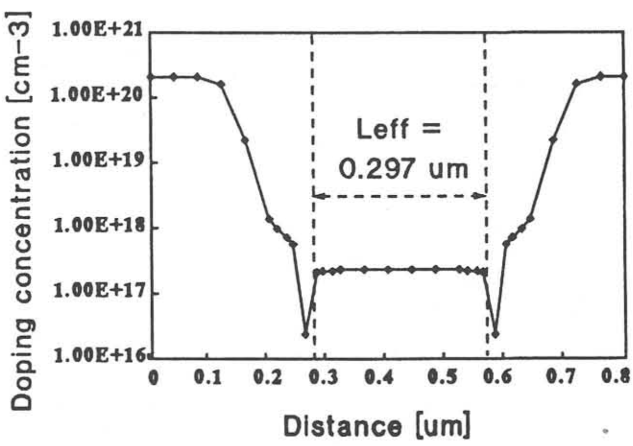

Fig.4 Doping concentration along the channel and Leff extracted from the corresponding Id-Vg curives by the new method. Device simulator, MEDICI is used.

4. CONCLUSION

A novel L_{eff} and R_{ext} extraction method has been proposed and evaluated by an experiment and a 2D device simulation for devices of a 0.4 μm CMOS technology. The method extracts V_g-independent L_{eff} and V_g-dependent R_{ext} in a completely self-consistent manner, based upon a device physically sound bases. The experiment demonstrated a resolution as high as 0.003 μm. The simulation showed that the extracted L_{eff} coincided with the plateau of the impurity profile within the accuracy of the simulation (approximately 0.02 μm). The new method is promising for the deep-submicron to sub-0.1 μm generation MOSFET's.

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