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## Accurate Extraction of Mobility, Effective Channel Length, and Source/Drain Resistance in 60 nm MOSFETs

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### Abstract

An improved channel resistance method is proposed to extract gate bias dependent source and drain series resistance ( $R_{SD}$ ), effective channel length ( $L_{eff} = L_{mask} - \Delta L$ ), and mobility. A nonscaling of the total resistance  $R_{TOT} = V_{DS}/I_{DS}$  of short channel device is observed because of mobility degradation of the short channel MOSFETs. The proposed method considers the variation of the effective mobility as a function of channel length.

### 1. Introduction

The effective mobility ( $\mu_{eff}$ ) is a key parameter that characterizes the transport in MOS transistors. Various improvements of the technique have been proposed to extend its applicability to ultrasmall MOSFETs with very thin oxides featuring significant gate leakage [1] or to short channel devices where overlap capacitances perturb the measurements [2]. In this paper, we measured the gate-channel intrinsic capacitance to get the actual inversion charge [3]. In the above method, the effective channel length and source and drain series resistance are critical parameters. Many methods of extracting  $R_{SD}$  and  $L_{eff}$  from DC have been reported [4]-[5]. However, these methods do not consider the variance of  $\mu_{eff}$  with gate length which introduces errors due to the halo (or pocket) implants in the fabrication process. The short channel MOSFET features a degraded effective mobility compared to the long channel reference device. The typical behavior of  $R_{TOT}$  as a function of  $L_{mask}$  is shown in Fig. 1. Consequently, the negative value of  $\Delta L$  or no intercept point is observed. In this paper, we propose an iteration method to extract  $R_{SD}$  and  $L_{eff}$  as a function of gate-source bias and this method was applied to 60 nm channel length devices.

### 2. Experimental Results and Discussions

Parameters were measured to extract gate-to-channel capacitance ( $C_{gc}$ ). The total measured  $C_{gc}$  is the sum of the parasitic  $C_p$  ( $C_{ov}$ ,  $C_{if}$ , and  $C_{of}$ ) and the intrinsic channel capacitance ( $C_{gci}$ ) (see insert of Fig.2). Fig. 2 shows typical  $C_{gc}(V_{gs}, L)$  characteristics as obtained on Si nMOSFETs of various gate lengths. Because of the dependency of gate voltage of  $C_{do}$  in short channel device, the  $C_{gc}(V_{gs}, L)$  curves shown in Fig. 2 correspond therefore to

$$\begin{aligned} C_{gc}(V_{gs}, L) &= (C_{of}, C_{do})_{at\ accumulation} + C_{if}(V_{gs}) + C_{do}(V_{gs}) & \dots \varphi_s < \varphi_B \\ C_{gc}(V_{gs}, L) &= (C_{of}, C_{do})_{at\ accumulation} + C_{if}(V_{gs}) + C_{do}(V_{gs}) + C_{gci}(V_{gs}, L) & \dots \varphi_B < \varphi_s < 2\varphi_B \\ C_{gc}(V_{gs}, L) &= (C_{of}, C_{do})_{at\ accumulation} + C_{do}(V_{gs}) + C_{gci}(V_{gs}, L) & \dots 2\varphi_B < \varphi_s \end{aligned}$$

The  $C_p$  and  $C_{gci}$  are extracted from  $C_{gc}(V_{gs}, L)$  as in Fig. 3. The inversion charge  $Q_i$  was obtained by integration of  $C_{gci}$  as a function of  $V_{gs}$  [3]. Fig. 4 (a) shows the inversion charge  $Q_i$  versus  $(V_{gs} - V_{th})$  at  $V_{ds} = 0$  for different channel lengths. Fig. 4 (b) shows the effective mobility which is deduced from

$$\mu_{eff} = \frac{(L_{mask} - \Delta L)^2 I_{ds}}{Q_i [V_{ds} - I_{ds} (R_s + R_d)]} \quad [1]$$

where we assume that the  $\Delta L$  and  $R_{SD}$  are 20nm and 1.5 $\Omega$  respectively which is initial guess. The strong degradation of extracted  $\mu_{eff}$  for different channel length is observed. This mobility variation in the short channel devices was compensated in the  $R_{TOT}$  measurement data to extract accurate  $\Delta L$  and  $R_{SD}$ . Fig. 5 shows the L-array method before mobility compensation and after mobility compensation. We re-extract the effective mobility using second  $\Delta L$  and  $R_{SD}$ . Fig. 6 shows convergence to the common intercept point for different initial guess points. Fig. 7 shows the extracted  $R_{SD}$  and  $\Delta L$  for different  $V_{gs} - V_{th}$  using the proposed method. This method takes into account the bias dependence of  $R_{SD}$  and  $\Delta L$ . Fig. 8 shows the effective mobility versus effective electric field ( $E_{eff} = (V_{gs} + V_{th})/6t_{ox}$ ).

### 3. Conclusion

We proposed an improved L-array method in 60 nm nMOSFETs, which includes the variance of effective mobility with gate length. Accurate values of  $\Delta L$  and  $R_{SD}$  were extracted in 60 nm MOSFETs. This method proves very useful for transport modeling in ultra-short channel devices.

### Acknowledgements

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### References

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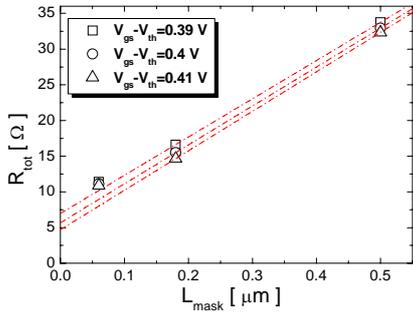


Fig. 1.  $R_{TOT}$  at the same gate overdrive. Dashed lines represent the linear regression of  $R_{TOT}$ .

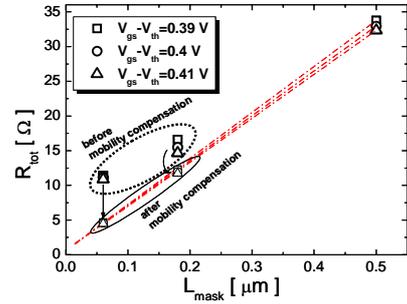


Fig. 5. The L-array method before mobility compensation and after mobility compensation.

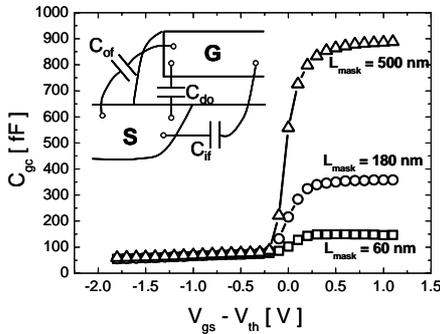


Fig. 2. Gate to channel capacitance obtained from nMOSFETs.

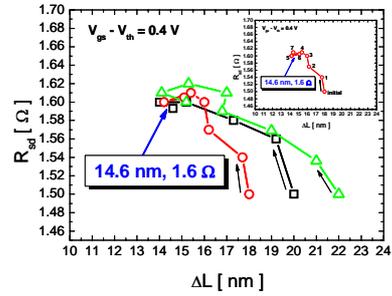


Fig. 6. The common intercept point of several lines, each for a different  $V_{gs}-V_{th}$  during iteration above method with various initial  $\Delta L$  and  $R_{sd}$  value.

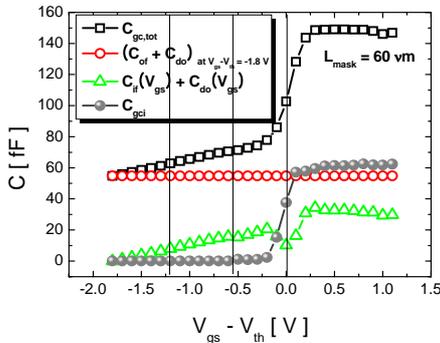


Fig. 3. The  $C_p$  ( $C_{ov}$ ,  $C_{if}$ , and  $C_{outf}$ ) and  $C_{gcl}(V_{gs}, L)$  are extracted from  $C_{gc}$ .

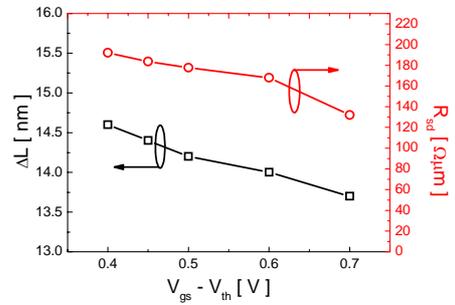


Fig. 7. The extracted  $R_{SD}$  and  $\Delta L$  for different  $V_{gs}-V_{th}$  using the proposed method.

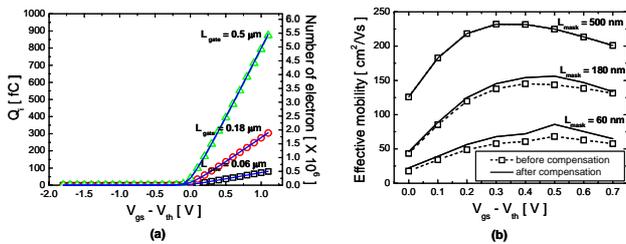


Fig. 4. (a) Inversion charge in the channel at  $V_{ds} = 0$  V. (B) Extracted effective mobility when the  $\Delta L$  and  $R_{SD}$  are 20 nm and 1.5  $\Omega$ , respectively.

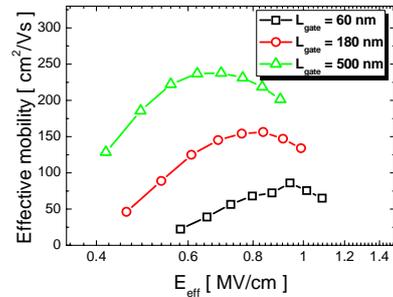


Fig. 8. The effective mobility versus effective electric field.