HiSIM-1.2 Parameter Extraction with the Revised UTMOST-III Local Optimization Strategies

1. Introduction

HiSIM-1.2 parameter extraction methodology was discussed in detail in a previous issue of Silvaco *Simulation Standard* [1]. This article is meant to provide the precise ***UTMOST-III*** local optimization strategies to *UTMOST-III* users who are interested in HiSIM-1.2 parameter extraction. The developed strategies were applied to the actual 90 nm technology devices [2]. The HiSIM-1.2 proved the capability to give the scalable model down to 100 nm from 10 um channel length with no parameter binning.

HiSIM-1.2 model parameters [3] are capitalized with the bold letters in this article.

2. Required Geometries for the Parameter Optimization

As the HiSIM model is based on the device physics [3], the geometry selection is quite significant to obtain the scalable parameter set. Large device with the long and wide channel is the starting point. Then, the length array(L-array) devices with the varied channel lengths under the fixed width should be prepared, preferably under the wide width, if the width dependent leakage current such as due to a shallow trench isolation (STI) isn't prominent. The channel length spacing should be small enough to represent the channel length effects such as a reverse short channel (RSC) and a short channel (SC) effects. The HiSIM-1.2 RSC and SC parameter extractions are found to require the threshold voltage dependency on the channel length, even though no explicit threshold voltage parameter is used in HiSIM-1.2 [1].

The width array (W-array) devices with the varied channel widths under the fixed length are also necessary. The small devices are used for the model verification, not for the parameter extractions. Neither dedicated parameters for small devices nor the parameter binning are defined in HiSIM-1.2.

3. Required Current Voltage Characteristics

Id/Vg at several drain voltages with the varied body biases should be measured. The drain voltages should cover the low linear, the linear to the saturation transition and the saturation regions. Id/Vd at several body voltages under the operating voltage range are used mainly for the high field mobility tuning. Most of HiSIM-1.2 parameter extractions are done with Id/Vg curves.

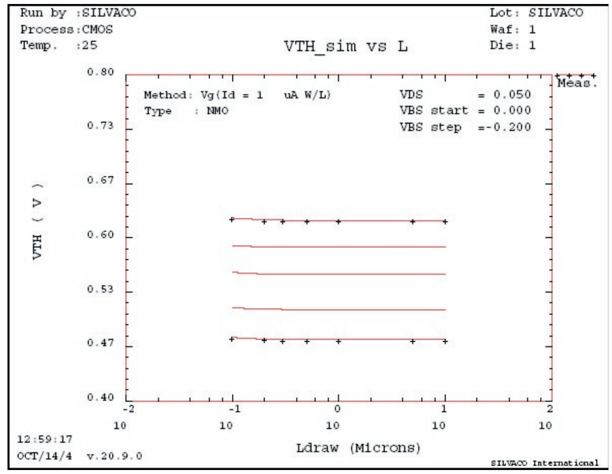

Figure 1. The NSUBP is the same as the NSUBC with 1e-6 of the LP.

The threshold voltage versus the channel length plot should be observed at key steps described detail in below such as # 30: idvg_large_HiSIM, #31: idvg_middle_HiSIM, #32: idvg_short_HiSIM, and #33: idvg_highVT_HiSIM.

UTMOST-III Validate routine [4] is useful to review the Vth vs. Ldraw Curves.

4. *UTMOST-III* Local Optimization Strategy Description

A. User Initial Input Parameters

The TOX must be defined by the user. Also, the LP value should be put as the initial guess according to the threshold voltage versus the channel length characteristics. There would be two inflection points. The reverse short channel region would be slightly concave with the threshold voltage roll-up, while the transition of the voltage roll-up to the roll-off area would be rather convex.

The LP initial value should be selected inside the concave portion where the slope of the threshold voltage roll-up increases in comparison to the longer channel length devices, or becomes pronounced. And the HiSIM-1.2 users should recognize no structural constraint exists for the LP value [1], even though the name is given as pocket penetration length [3].

The other HiSIM-1.2 parameters should be the default values described in HiSIM-1.2 users manual [3].

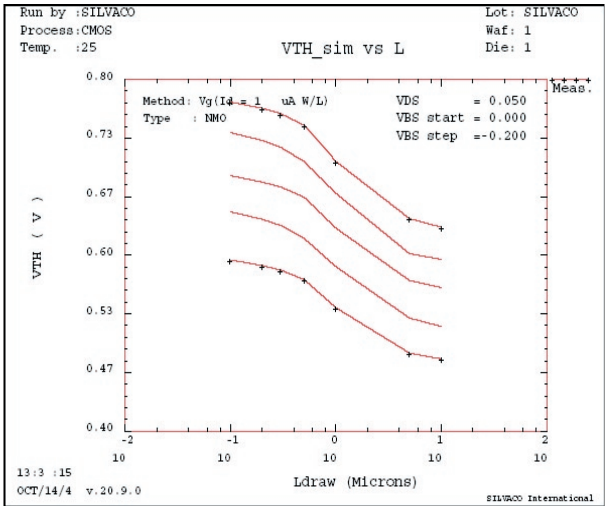

Figure 2. The larger NSUBP value than that of the NSUBC is specified.

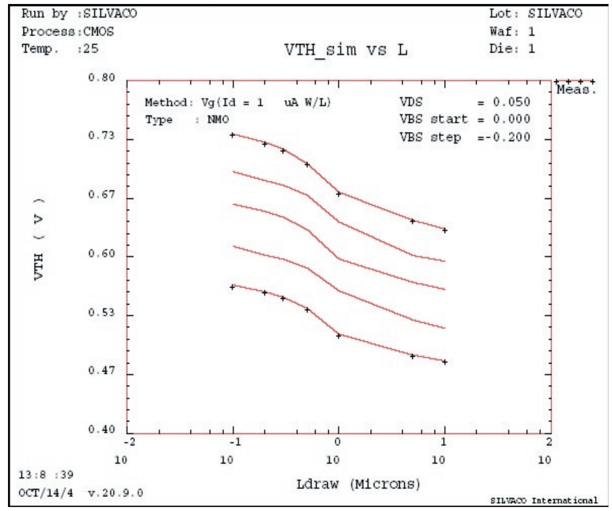

Figure 3. The SCP1 modifies the Vth roll-up phenomenon at the shorter channel length than the LP(1e-6). The SCP1 is arbitrary to highlight the effect.

B. Strategy Definition

30: idvg_large_HiSIM

parameters: NSUBC and VFBC

target: Id/Vg at the low linear region(at the low Vds) with the narrow drain current range around the onset of the strong inversion (threshold voltage region) to avoid STI leakage region

geometry: the large device

NOTE:

The parameter effects are as following.

VFBC: entire Id/Vg curve shift

NSUBC: both entire curve and the body effect shifts

The NSUBP should be linked to the NSUBC as the ratio of one during the optimization in order to set the initial value of the NSUBP. The NSUBC should be optimized several times after the following “#31: idvg_middle_HiSIM strategy” which optimizes the NSUBP, so that the total substrate concentration is modified.

#31: idvg_middle_HiSIM

parameters: NSUBP, SCP1, SCP3, (LP)

target: same as #30 strategy

geometries: NSUBP for the reverse short channel effect (RSCE) devices which have the longer channel length than the LP value. SCP1 and SCP3, the RSCE devices with the shorter length than the LP point

NOTE

The step is quite significant.

The NSUBP is for the Vth roll-up tuning. And the NSUBP value influences the averaged substrate concentration [3] which modifies the large device Id/Vg curve. Optimize the NSUBC and the NSUBP several times to meet the threshold voltage regions for both the large and the middle devices.

The SCP1 is for the convex part of the RSCE on the threshold voltage versus the channel length plot. The transition from the concave to the convex shape occurs around the LP point. The initial value of LP might require the re-optimization to match the transition. Just use the LP only for the purpose.

The SCP3 is related to the Vbs in the equation of the RSCE lateral field gradient equation [3]. However, the SCP3 could have the larger effect than the SCP1 for the entire RSCE, not only for the high Vbs region, which depends on the balance of the SCP1 and the SCP3 values. The high Vbs region for the RSCE devices using the SCP3 could become a bit insufficient fit which might need further investigation.

#32: idvg_short_HiSIM

parameters: PARL2, SC1, SC3

target: same as #30 strategy

geometry: the short channel effect (SCE) devices

NOTE:

The inflection point of the threshold voltage shift from the RSCE to the SCE could become difficult to be expressed with them. In that case, try the different value of the LP. If the Vth vs. Ldraw simulation curves could resemble the data, re-optimize the NSUBP under the new LP. In that case, the NSUBC should also be optimized again.

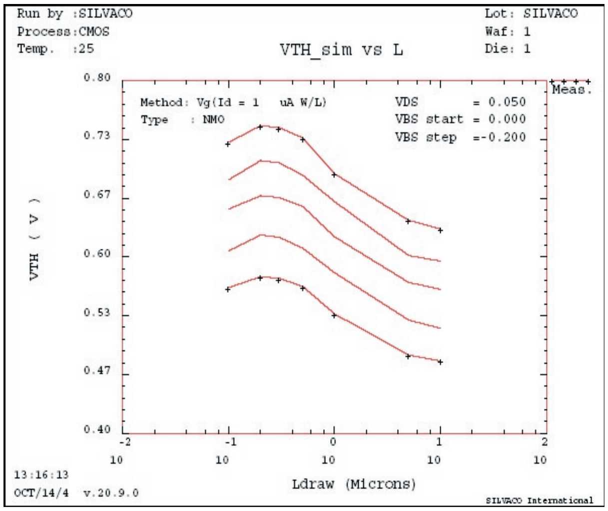

Figure 4. The SC1 expresses the standard short channel effect(Vth roll-off).

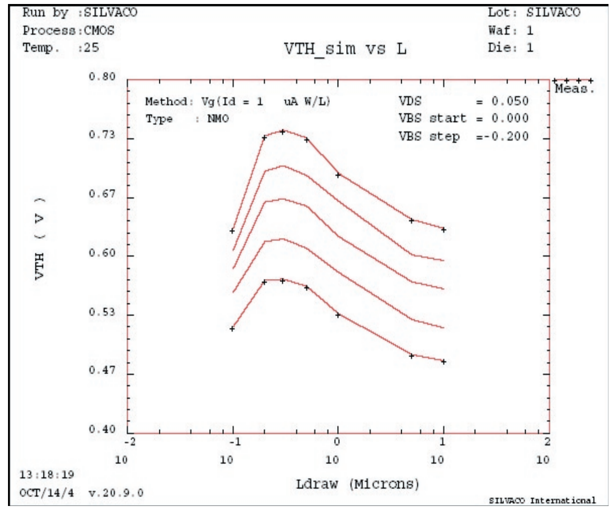

Figure 5. The SC3 modifies the Vth roll-off mainly for the body bias region.

As of the SCP1 and SCP3 relation, the SC1 and the SC3 have the compatible effect on the characteristics.

#33: idvg_highVT_HiSIM

parameters: SC2, SCP2

target: Id/Vg at the saturation region(at the high Vds) The drain current region is the same as #30 strategy.

geometry: the reverse short channel effect devices for SCP2 with the short channel effect devices for SC2

NOTE:

Watch the Vth vs. Ldraw simulations for the high drain bias region.

#34: idvg_lowMue_HiSIM

parameters: MUECB0, MUECB1, MUEPH1, MUESR1

targets: Id/Vg at the low linear region(at the low Vds) MUECB0 for the subthreshold region, avoid the STI leakage part MUECB1 for the on-set of strong inversion MUEPH1 for around the maximum slope of Id/Vg curve MUESR1 for the degradation of Id/Vg at the high Vgs

geometries: large and sometimes large middle devices which show the small threshold voltage roll-up.

NOTE:

Observe the short channel characteristics during the optimization. Even though the large device would be sufficient, the shorter ones might not. Tuning the bias region might be required. Or, the HiSIM substrate parameters, the RSC and the SC parameters might be insufficient. The threshold voltage vs. the channel length should be observed carefully. Because the HiSIM low field mobility model depends on the vertical electric field which are determined by the previously optimized parameters.

With these optimization steps completed, the Id/Vg curves at the low linear region simulated by HiSIM-1.2 should fit well to the measurement data.

Users could use the strategy #34 right after the strategy #30 to get the initial value. Because the HiSIM-1.2 default parameter values are for N channel devices.

#35: idvg_highVD_HiSIM

parameters: VMAX, VOVER, VOVERP

targets: Id/Vg at the saturation region(at the high Vds) with the strong inversion region geometries: the short channel effect devices

NOTE:

HiSIM-1.2 high field mobility adjustment appears to be rather manageable with Id/Vg at the saturation region than using Id/Vd characteristics. However, the Id/Vd curves at the saturation region could be used as the optimization targets. The acceptable optimization fit should be obtained fairly easily. If not, the users should review the previous optimization results through the threshold voltage versus the channel length plot. Because, the high field mobility depends both on the low field component and the lateral electric field. The Vth shift with the channel length is the significant index of the electric field effect.

#36: idvg_narrow_HiSIM

parameters: WFC

targets: Id/Vg at the linear region(at the low Vds) with the threshold voltage region, avoid the STI leakage region

geometries: the narrow channel effect devices

NOTE:
Only one parameter for the threshold voltage roll-off due to the narrow channel effect is prepared in HiSIM-1.2.

#37: idvg_STI_HiSIM

parameters: WVTHSC, NSTI, WSTI

targets: Id/Vg at the linear region, or the saturation region with the current hump area in the subthreshold region geometries: the short channel devices

NOTE:
The hump leakage characteristics due to the STI can be expressed with these parameters. But the users should be careful to varify various devices.

5. Observation of HiSIM-1.2 Parameter Effects

Threshold voltage versus channel length plot has been referred frequently as the index of the electric field effect of HiSIM-1.2 in this article. The following figures will illustrate the HiSIM-1.2 parameter influence on the threshold voltage versus channel length (Ldraw) using ***UTMOST-III*** Validate routine [4].

6. Summary

UTMOST-III local optimization strategies for HiSIM-1.2 model were developed. Although no explicit threshold voltage parameter is used in HiSIM-1.2, the modeling engineer has to specify the target current range around the threshold voltage region for most of the parameter optimization steps, especially for devices with the STI effects.

As HiSIM-1.2 model behavior strictly follows the electric field, and the gradient expression of MOSFET devices, the users should take care of the substrate related parameters.

6. Acknowledgments

The author would like to thank Prof. Mitiko Miura-Mattauch, Hiroshima Univ., Japan, for her valuable suggestion in pointing the significance to track the threshold voltage behaviors during the parameter optimization steps.

Also, he would like to express the gratitude to Semiconductor Technology Academic Research Center (STARC) for allowing to use the device data for HiSIM-1.2 parameter extraction development.

7. References

[1] "HiSIM Methodology for the Parameter Extraction in Accordance with the Model Derivation", Silvaco International-Simulation Standard, vol. 13, no 7, July 2003 (http://www.silvaco.com)

[2] Y. Iino, "A Trial Report: HiSIM-1.2 Parameter Extraction for 90 nm Technology", 2004 Workshop on Compact Modeling, WCM 2004, in association with 2004 NSTI Nanotechnology Conference and Trade Show (http://www.nsti.org)

[3] "HiSIM1.2.0 User's manual", Semiconductor Technology Academic Research Center(STARC), 2003 (http://www.starc.or.jp/kaihatu/pdgr/hisim/index.html)

[4] Silvaco International,UTMOST-III Extractions Manual, vol.1 (Decemeber 2002)