CALIBRATION OF A MOBILITY MODEL FOR QUARTERMICRON CMOS DEVICES

T. Grasser, R. Strasser, M. Knaipp, K. Tsuneno[†], H. Masuda[†], and S. Selberherr

Institute for Microelectronics, TU Vienna
Gußhausstraße 27–29, A–1040 Vienna, Austria
Phone: +43/1/58801-3859, Fax: +43/1/5059224,
e-mail: grasser@iue.tuwien.ac.at, URL: http://www.iue.tuwien.ac.at

[†]Hitachi, Ltd., 16-3, Shinmachi 6-Chome, Ome-shi, Tokyo 198-8512, Japan

ABSTRACT

We present the calibration of a mobility model for a 0.25μm CMOS technology using response surface methodology. For this process several measurements for different gate lengths (0.2μm - 4.0μm) were made. Care was taken to eliminate the statistical variations typical to sub-micron devices by measuring several chips on the the same wafer and taking an average sample.

INTRODUCTION

During the past decade numerous highly effective simulators for the simulation of semiconductor technology (e.g., TSUPREM4 (TMA 1995)), as well as semiconductor devices (e.g., MINIMOS (Fischer et al. 1994), MEDICI (TMA 1994)) have been developed. These simulators deliver reasonable and accurate predictions of process and device performance. Nevertheless, the models implemented in these simulators employ a vast number of not too well known parameters. Furthermore, due to the complex nature of the underlying physics, it is very difficult to develop models with parameters that are valid for all operating conditions.

THE MINIMOS MOBILITY MODEL

In this subsection the expressions representing the MINIMOS electron mobility model for silicon are summarized. All temperature dependencies are left unconsidered. A more detailed discussion can be found in (Selberherr et al. 1990).

To account for the mobility reduction due to ionized impurity scattering a classical formula is used.

$$\mu_n^{LI} = \mu_n^{min} + \frac{\mu_n^L - \mu_n^{min}}{1 + \left(\dfrac{CI}{C_n^{ref}}\right)^{\alpha_n}} \tag{1}$$

Surface scattering is modeled by the following empirical expression:

$$\mu_n^{LIS} = \frac{\mu_n^{ref} + (\mu_n^{LI} - \mu_n^{ref}) \cdot (1 - F(y))}{1 + F(y) \cdot \left(\dfrac{S_n}{S_n^{ref}}\right)^{\gamma_n}} \tag{2}$$

The pressing force S_n is equal to the magnitude of the normal field strength at the interface, if the carriers are attracted by the interface, otherwise zero. The depth dependence is modeled as follows:

$$F(y) = \frac{2 \cdot \exp\left(-\left(\dfrac{y}{y^{ref}}\right)^2\right)}{1 + \exp\left(-2 \cdot \left(\dfrac{y}{y^{ref}}\right)^2\right)} \tag{3}$$

Deviations from the ohmic low-field mobility are given by

$$\mu_n^{LISF} = \frac{2 \cdot \mu_n^{LIS}}{1 + \left(1 + \left(\dfrac{2 \cdot \mu_n^{LIS} \cdot F_n}{v_n^{sat}}\right)^{\beta_n}\right)^{1/\beta_n}} \tag{4}$$

and

$$F_n = \left| \text{grad } \psi - \frac{1}{n} \cdot \text{grad } (U_{Tn} \cdot n) \right| \tag{5}$$

Here F_n represents the driving force for electrons and U_{Tn} is the electron thermal voltage.

Investigation of the Mobility Model Parameters

The ionized-impurity scattering parameters μ_n^{min} and C_n^{ref} are considered to be sufficiently accurate. The surface scattering and high field mobility parameters depend stronger on the fabrication process. To yield physically meaningful results, valid for a large range of gate lengths, appropriate devices and bias conditions must be selected during the calibration. After disabling the high field mobility degradation term (4), the error in the maximum drain current of the 4μm device was found to be about 2%. Hence, it was decided to calibrate the surface mobility parameters using this long-channel device. With these values, the calibration of the high field mobility parameters was done with the short channel device, where a strong high-field degradation could be expected.

ACTUAL CALIBRATION

Before performing any calibrations on the $4\mu m$ device, the simulation results obtained by using the default mobility parameters were compared with measurements. To account for the unknown interface charges, the work function difference was adjusted to $E_w = -0.6eV$ to reproduce a current of $I_d(V_{th}) = 10nA$ for the measured threshold voltage of $V_{th} = 0.15V$, since the influence of the surface and high field mobility parameters on the drain current are negligible under these bias conditions. As expected, the comparison shows good agreement for the sub-threshold region, whereas the drain current for maximum bias is overestimated by 17%.

Surface Mobility Parameters

After a sensitivity analysis for the three surface mobility parameters μ_n^{ref}, y^{ref}, and γ_n for the $4\mu m$ device, the ranges for a central composite circumscribed design (Lorenzen and Anderson 1991) were set up. The calibration was automatically run using our VISTA framework (Pichler et al. 1997) with fifteen operating points selected from the measured IV-curves. Using the optimized parameters for the simulation, the resulting maximum absolute error in the drain current was found to be less than 2.3% in the entire range.

High Field Parameters

Before concentrating on the high field parameters, the optimum parameters extracted with the $4\mu m$ device were tested for their accuracy when used for the $0.25\mu m$ device. As before, only the threshold voltage has been adjusted to satisfy the threshold condition. This adjustment ($E_w = -0.53eV$) is necessary to compensate the inaccuracies of the process simulation for deep-submicron devices. The agreement was found to be exceptionally good. For high-bias conditions, the drain current is overestimated by only 2%. This corresponds well with the expected behavior. Because the parameters predicted the measurement data well already, the design of experiments was prepared carefully. The drain current was tested for the sensitivity to each parameter, to provide the optimizer, using a response surface method, with a narrow and accurate range. But, since the high-field region is under consideration, the selected fifteen operating points were restricted to these high bias regions.

With the optimized values the simulation shows a very small error (0.7%) for the higher bias conditions and a little larger error (2.4%) for intermediary bias conditions. The optimum found is summarized in Table 1. All parameters show physically sound deviations from their respective default values.

Global Accuracy

To test the accuracy of these values for devices with even shorter gate lengths, simulations with the $0.2\mu m$ device were carried out. Again, the accuracy is very good considering the large uncertainty of the process data for such small gate lengths. The final results for the $L_g = 4\mu m$, $L_g = 0.25\mu m$, and the $L_g = 0.2\mu m$ devices using the calibrated values are shown in the Fig. 1 - Fig. 3.

Par.	Optimum	Default	Deviation[%]	Unit
μ_n^{ref}	538	638	-15.7	cm^2/Vs
y^{ref}	3.96	10	-60	nm
γ_n	1.33	1.69	-21.3	1
S_n^{ref}	5.933e7	7e7	-15.2	V/m
v_n^{sat}	1.48e7	1.45e5	2	cm/s
β_n	2.217	2	10.8	1

Table 1: Mobility model parameters

DISCUSSION

The change of the nominal model parameters to their optimized values is quite small. Many uncertainties in the exact doping profile, gate length, etc., the calibrated parameters reflect the average variations of these process parameters.

ACKNOWLEDGMENT

This work is supported by the "Christian Doppler Forschungsgesellschaft", Vienna, Austria, and by SIEMENS, EZM Villach, Austria.

REFERENCES

Fischer, C.; Habaš, P.; Heinreichsberger, O.; Kosina, H.; Lindorfer, P.; Pichler, P.; Pötzl, H.; Sala, C.; Schütz, A.; Selberherr, S.; Stiftinger, M., and Thurner, M. 1994. *MINIMOS 6 User's Guide.* Institut für Mikroelektronik Technische Universität Wien, Austria.

Lorenzen, T. and Anderson, V. 1991. *Design of Experiments.* Marcel Dekker.

Pichler, C.; Plasun, R.; Strasser, R., and Selberherr, S. 1997. High-Level TCAD Task Representation and Automation. *IEEE Trans.Semiconductor Technology Modeling and Simulation.* http://www.ieee.org/journal/tcad/accepted/pichler-may97/.

Selberherr, S.; Hänsch, W.; Seavey, M., and Slotboom, J. 1990. The Evolution of the MINIMOS Mobility Model. *Solid-State Electron.* 33(11):1425–1436.

TMA 1994. *TMA MEDICI, Two-Dimensional Device Simulation Program, Version 2.0.* Technology Modeling Associates, Inc. Palo Alto, CA.

TMA 1995. *TMA TSUPREM-4, Two-Dimensional Process Simulation Program, Version 6.2.* Technology Modeling Associates, Inc. Palo Alto, CA.

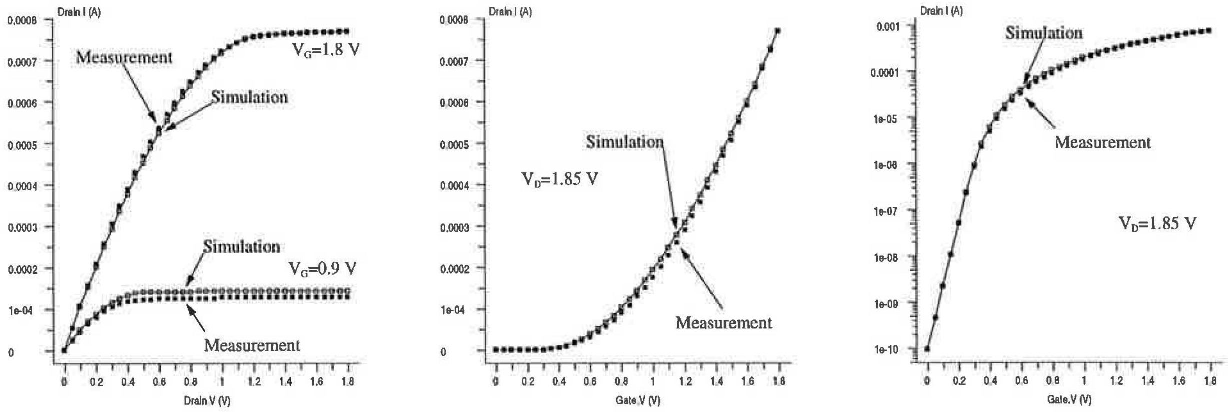

Figure 1: Comparison of simulation and measurement for the $L_g = 4\mu m$ device.

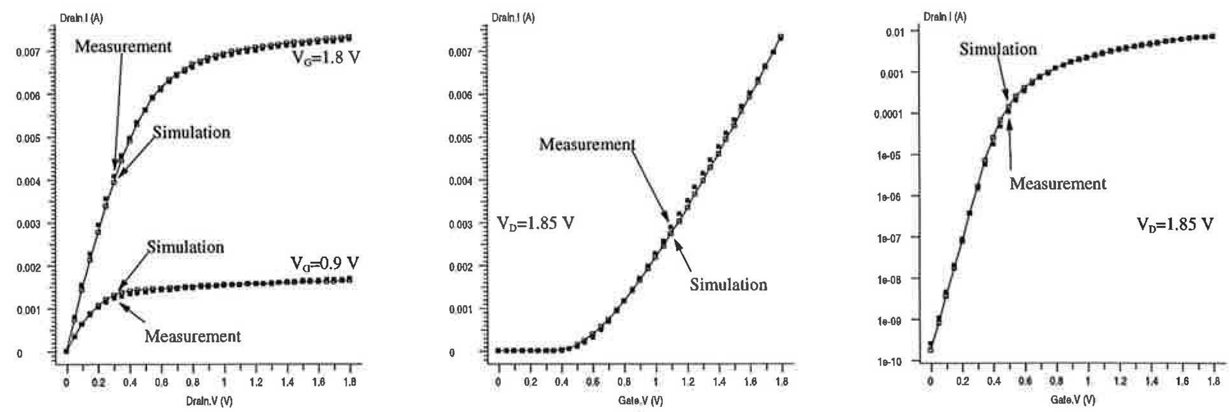

Figure 2: Comparison of simulation and measurement for the $L_g = 0.25\mu m$ device.

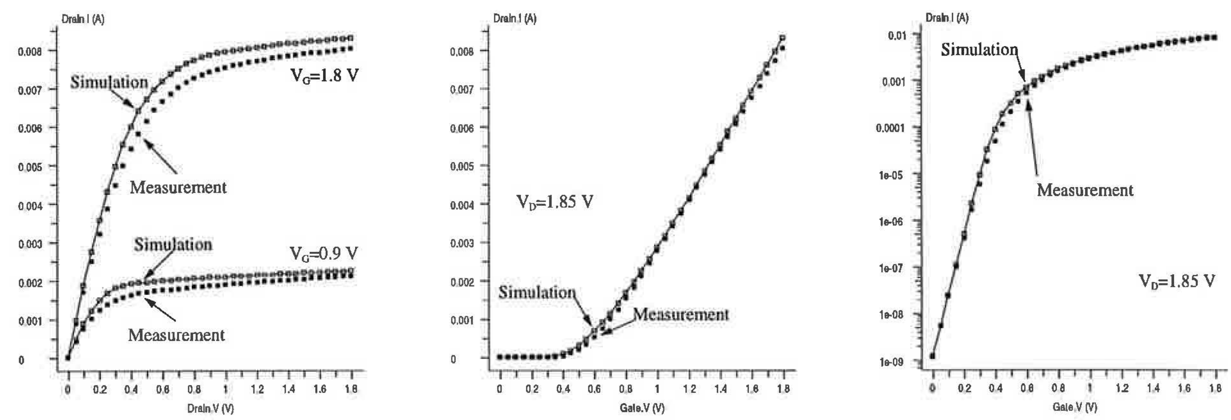

Figure 3: Comparison of simulation and measurement for the $L_g = 0.2\mu m$ device.