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A SYSTEMATIC APPROACH FOR MODEL EXTRACTION FOR DEVICE SIMULATION APPLICATION

V. Palankovski, R. Strasser, H. Kosina, and S. Selberherr

Institute for Microelectronics, TU Vienna,
Gusshausstrasse 27–29, A-1040 Vienna, Austria
Phone: +43/1/58801-36017, Fax: +43/1/58801-36099,
E-mail: Vassil.Palankovski@iue.tuwien.ac.at

ABSTRACT

We present an approach for model parameter extraction for the two-dimensional simulator MINIMOS-NT. Experimental data are used as a basic input. Furthermore, accurate Monte-Carlo (MC) simulations deliver information which is still experimentally missing or inconsistent. An optimizer which is part of our TCAD environment is then applied to calibrate parameters of an initially chosen functional form to the input data. As a result we obtain analytical models with high accuracy and wide range of validity.

Keywords: Monte-Carlo methods, models, simulation, mobility

1 INTRODUCTION

Though numerous theoretical and experimental papers [1, 2, 3] on electron mobility in semiconductors have been published there are still some issues under discussion, particularly in the very high doping regime. The difference between majority and minority electron mobility is a well-known phenomenon caused by effects such as degeneracy and the different screening behavior of electrons and holes in semiconductors. However, the mobility models usually employed in device modeling do not reflect these facts. Aim of the present work was to construct an analytical model capable of describing electron mobility under arbitrary doping conditions.

As an example we present automated parameter extraction using an optimizer [4] for the mobility models in MINIMOS-NT [5]. Most of the existing experimental data on the low-field mobility together with accurate MC simulations for Si [6] and for III-V semiconductor compounds [7, 8, 9] are used as input.

2 THE FUNCTION USED

To account for mobility reduction due to ionized impurity scattering, the formula of Caughey and Thomas [10] is widely used in conjunction with temperature dependent coefficients.

$$\mu^{\mathrm{LI}} = \mu_1 + \frac{\mu^{\mathrm{L}} - \mu_1}{1 + \left(\frac{C_{\mathrm{I}}}{C_1}\right)^{\alpha}} \tag{1}$$

Although initially proposed for the majority electron mobility in Si [11], we found that

$$\mu_n^{\mathrm{LI}} = \frac{\mu_n^{\mathrm{L}} - \mu_1 - \mu_2}{1 + \left(\frac{C_{\mathrm{I}}}{C_1}\right)^{\alpha}} + \frac{\mu_1}{1 + \left(\frac{C_{\mathrm{I}}}{C_2}\right)^{\beta}} + \mu_2 \tag{2}$$

offers enough flexibility to model also the minority electron mobility in Si (see Fig. 1). In general, it can be applied also for any other material of interest (Fig. 2, Fig. 3). (2) is similar to (1), a function with two extreme values (μ^{L} as a maximum and μ_1 as a minimum mobility). (2) is a mathematical function which can deliver a second maximum or minimum at very high impurity concentrations depending on the sign of μ_1. Thus, it allows both majority and minority carrier mobilities to be corectly modeled.

The temperature dependence of the lattice mobility μ_n^L, and of the parameters μ_1, μ_2, C_1, C_2, α, and β is modeled by simple power laws. C_I denotes the concentration of ionized impurities.

3 MODEL PARAMETER EXTRACTION

A model which distinguishes between the majority and minority electrons in Si, as well as between dopant species is described in [12]. We use much simpler expressions to achieve the same mobility values and therefore

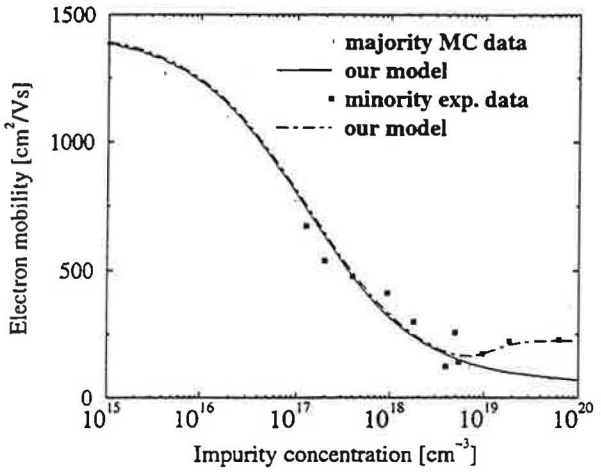

Figure 1: Comparison of the analytical model and MC data for electron mobility in Si at 300 K

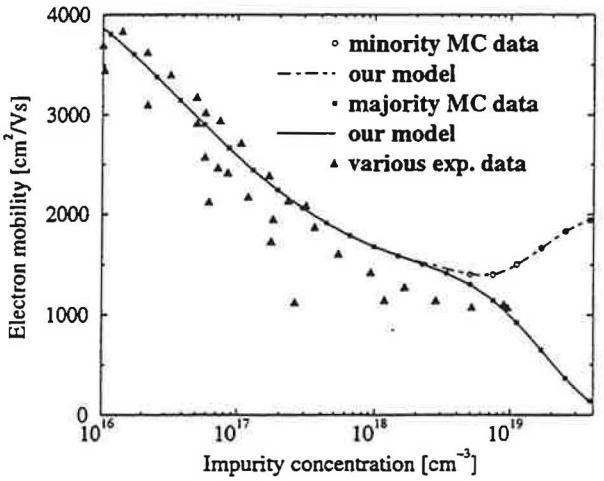

Figure 2: Comparison of the analytical model and MC data for electron mobility in InP at 300 K

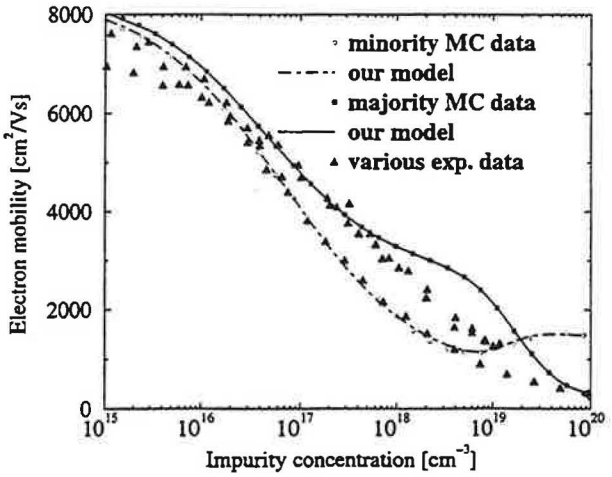

Figure 3: Comparison of the analytical model and MC data for electron mobility in GaAs at 300 K

saving computational effort and complications in the discretization. The temperature dependence of the lattice mobility preserves the expression used in the mobility model of MINIMOS [13]

$$\mu_n^{\mathrm{L}} = \mu_{300}^{\mathrm{L}} \cdot \left(\frac{T_L}{300\,\mathrm{K}}\right)^{\gamma_0}. \tag{3}$$

The coefficients of (2) in the case of majority electrons are

$$\mu_1 = \mu_{1,300}^{\mathrm{maj}} \cdot \left(\frac{T_L}{300\,\mathrm{K}}\right)^{\gamma_1} \tag{4}$$

$$\mu_2 = \mu_{2,300}^{\mathrm{maj}} \cdot \left(\frac{T_L}{300\,\mathrm{K}}\right)^{\gamma_2} \tag{5}$$

$$\alpha = \alpha_{300} \cdot \left(\frac{T_L}{300\,\mathrm{K}}\right)^{\gamma_3} \tag{6}$$

$$\beta = \beta_{300}^{\mathrm{maj}} \cdot \left(\frac{T_L}{300\,\mathrm{K}}\right)^{\gamma_4} \tag{7}$$

$$C_1 = C_{1,300} \cdot \left(\frac{T_L}{300\,\mathrm{K}}\right)^{\gamma_5} \tag{8}$$

$$C_2 = C_{2,300}^{\mathrm{maj}} \cdot \left(\frac{T_L}{300\,\mathrm{K}}\right)^{\gamma_6} \tag{9}$$

The minority electron mobility is modeled as a function of the acceptor concentration and the lattice temperature. The formula (2) is used with the same coefficients, just μ_1, μ_2, C_2, and β differ.

$$\mu_1 = \mu_{1,300}^{\mathrm{min}} \cdot \left(\frac{T_L}{300\,\mathrm{K}}\right)^{\gamma_7} \tag{10}$$

$$\mu_2 = \mu_{1,300}^{\mathrm{min}} \cdot \left(\frac{T_L}{300\,\mathrm{K}}\right)^{\gamma_8} \tag{11}$$

$$\beta = \beta_{300}^{\mathrm{min}} \cdot \left(\frac{T_L}{300\,\mathrm{K}}\right)^{\gamma_9} \tag{12}$$

$$C_2 = C_{2,300}^{\mathrm{min}} \cdot \left(\frac{T_L}{300\,\mathrm{K}}\right)^{\gamma_{10}} \tag{13}$$

The TCAD setup allows simultaneously to obtain parameters for several temperatures and concentrations (Fig. 4) with a minimum global error. For instance, for computing the parameters for the majority mobility in Si we used MC data for ten different temperatures, each containing the mobility values for from six to ten different dopings. Several model evaluations were performed to get the parameters giving a minimum relative error. In Fig. 5 and Fig. 6 the resulting fitting curves are shown for several temperatures. In Table 1 we summarize the parameter values obtained for Si, such as (2) delivers the results from Fig. 1. In comparison we show the values used in MINIMOS with (1). The corresponding coefficients do not differ significantly, which is quite understandable, as soon as at low and moderate doping both models are expected to deliver the same mobility values, and at high only the

additional term in (2) to deliver increase or reduction in the case of minority or majority electrons, respectively.

In Table 2 we present the values extracted for GaAs and InP at 300 K. In Fig. 2 we present the majority and minority electron mobility in InP at 300 K, obtained with our model and compared with experimental and MC simulation data. Fig. 3 depicts our model applied to GaAs with parameters obtained from the optimizer and compares it to measurements and the MC simulation results. The results confirm that the model is well suited for III-V materials.

Parameter	MINIMOS-NT	MINIMOS	Unit
μ_{300}^{L}	1430	1425	cm^2/Vs
γ_0	-2	-2	
$\mu_{1,300}^{maj}$	52	80	cm^2/Vs
γ_1	-0.18	-0.45	
$\mu_{2,300}^{maj}$	8	—	cm^2/Vs
γ_2	-1.49	—	
$\mu_{1,300}^{min}$	-200	—	cm^2/Vs
$\mu_{2,300}^{min}$	230	—	cm^2/Vs
α_{300}	0.70	0.72	
γ_3	0.02	0.065	
β_{300}^{maj}	5.33	—	
γ_4	-9.5	—	
β_{300}^{min}	2.0	—	
$C_{1,300}$	1.17e17	1.12e17	cm^{-3}
γ_5	3.55	3.2	
$C_{2,300}^{maj}$	5.8e20	—	cm^{-3}
γ_6	0.134	—	
$C_{2,300}^{min}$	1.0e19	—	cm^{-3}

Table 1: Low-field mobility parameter values for Si for the temperature range 70-500 K

4 CONCLUSION

We present a simple analytical function, sufficent to be used for modeling both the minority and the majority electron mobility in several semiconductor materials of interest. It is included in the device simulator MINIMOS-NT. Using model evaluation and optimization we extracted parameter values, such that a good agreement with experimental and MC results was achieved.

Parameter	GaAs	InP	Unit
μ_{300}^{L}	8400	5000	cm^2/Vs
$\mu_{1,300}^{maj}$	2590	1140	cm^2/Vs
$\mu_{2,300}^{maj}$	133	20	cm^2/Vs
$\mu_{1,300}^{min}$	-750	-742	cm^2/Vs
$\mu_{2,300}^{min}$	1400	1920	cm^2/Vs
α_{300}	0.7	0.6	
β_{300}^{maj}	1.7	2.5	
β_{300}^{min}	2.8	3.2	
$C_{1,300}$	0.5e17	4e16	cm^{-3}
$C_{2,300}^{maj}$	1.8e19	1.6e19	cm^{-3}
$C_{2,300}^{min}$	1.4e19	1.6e19	cm^{-3}

Table 2: Low-field mobility parameter values for GaAs and InP at 300 K

5 ACKNOWLEDGMENT

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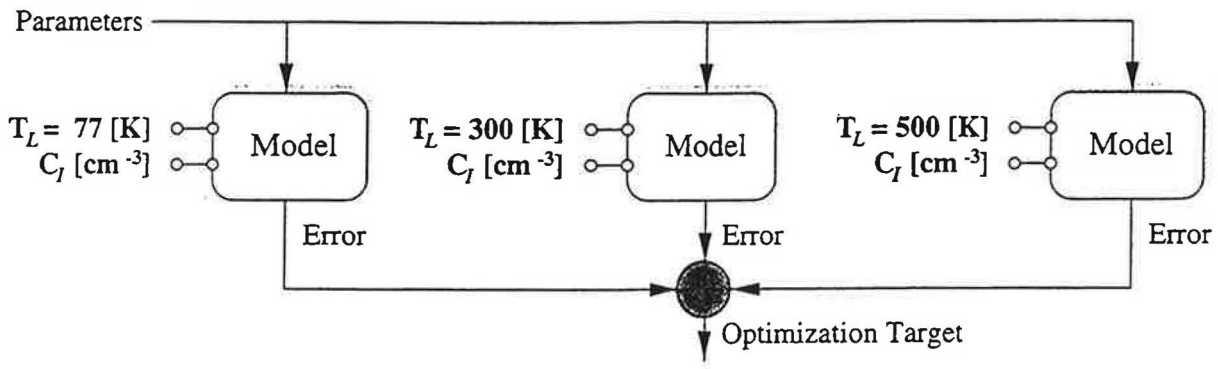

Figure 4: Simultaneous parameter extraction at different temperatures and concentrations

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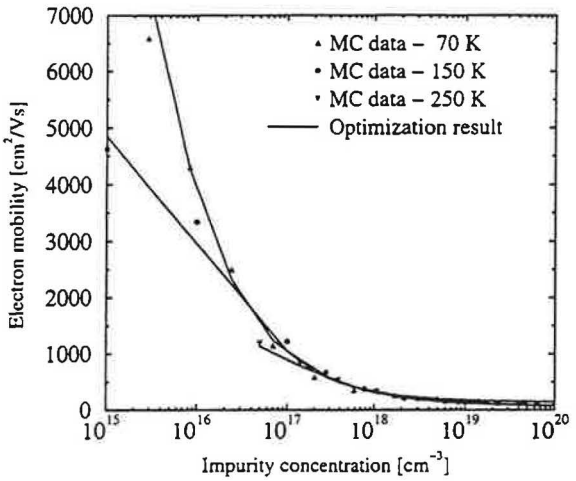

Figure 5: Optimization results for Si majority mobility at temperatures lower than 300 K

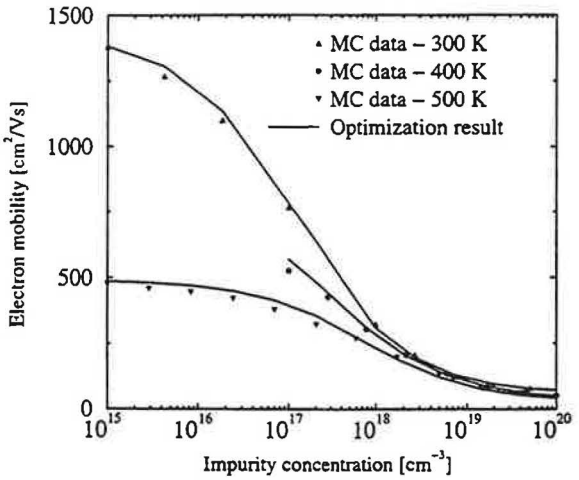

Figure 6: Optimization results for Si majority mobility at temperatures higher than 300 K