Student paper

A 2D-Non-Parabolic Six Moments Model

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The most accurate way to describe carrier transport is to solve the Boltzmann transport equation (BTE), for instance with the very time consuming Monte-Carlo (MC) technique. On an engineering level however macroscopic transport models are more efficient. Multiplication of the BTE with weight functions, approximation of the scattering integral with a macroscopic relaxation time and integration over k-space yields, for instance, the drift-diffusion model, the energy transport model, and the six moments model [1]. As demonstrated in [2] and [3] for the bulk case, a non-parabolic six moments model may be accurate down to $30\,\mathrm{nm}$. The challenge is to model higher-order transport parameters like the energy relaxation time τ_1, the second-order relaxation time τ_2, the energy mobility μ_1 and the second-order mobility μ_2 (see Figure 2) with as few simplifying assumptions as possible. A good choice is the use of tabulated. data extracted from MC simulations [4]. So far, bulk data has been used to examine higher-order parameters in a device. However, important effects like surface roughness scattering or the quantization in inversion layers are not included in bulk MC-data.

In order to account for these effects, a selfconsistently coupled Subband-Monte-Carlo simulator (SMC) and a Schrödinger-Poisson (SP) solver (see Figure 1) are applied. The SP solves the quantum confinement and the SMC simulates the 2D transport in each subband [5]. In order to be consistent with the 2D-parameters the approach consistently, we have developed a 2D-higher-order-transport model. The following equations yield the 2D and 3D transport model with D as the dimension of the system. With $D_0 = 1$, $D_1 = 1$, $D_2 = D/2$, $D_3 = (2+D)/2$, $D_4 = (2+D)D/2^{4-D}$, and $D_5 = (4+D)(2+D)/4$ the model reads

$$
\begin{aligned}
&\phi_0 : D_0 \partial_t n - \frac{1}{\mathrm{q}_0} \nabla_{\mathrm{r}} \mathbf{J_n} = 0\,,\\
&\phi_2 : D_2 \mathrm{k_B} \partial_t \left(n T_n\right) + \nabla_{\mathrm{r}} \mathbf{S}_n - \mathbf{E} \cdot \mathbf{J_n} = -D_2 n \mathrm{k_B} \frac{T - T_0}{\tau_1}\,,\\
&\phi_4 : D_4 \frac{\mathrm{k_B}^2}{m^*} \partial_t \left(n T_n^2 \beta\right) + \frac{2}{m^*} \nabla_{\mathrm{r}} \mathbf{K_n} + \frac{4\mathrm{q}_0}{m^*} \mathbf{E} \cdot \mathbf{S}_n = -D_4 \frac{n}{m^*} \mathrm{k_B}^2 \frac{T^2 - T_0^2}{\tau_2}\,,\\
&\phi_1 : \mathbf{J_n} = \mu_0 H_0 \left(D_1 \nabla_{\mathrm{r}} \left(\mathrm{k_B} n T_n\right) + h_0 \mathrm{q}_0 \mathbf{E} n\right)\,,\\
&\phi_3 : \mathbf{S}_n = -\mu_1 H_1 \left(D_3 \nabla_{\mathrm{r}} \left(n \frac{\left(\mathrm{k_B} T_n\right)^2}{q} \beta\right) + h_1 D_3 \mathrm{k_B} T_n \mathbf{E} n\right)\,,\\
&\phi_5 : \mathbf{K_n} = -\mu_2 H_2 \left(D_5 \nabla_{\mathrm{r}} \left(n \frac{\left(\mathrm{k_B} T_n\right)^3}{q} \gamma\right) + h_2 D_5 \left(\mathrm{k_B} T_n\right)^2 \mathbf{E} n \beta\right)\,.
\end{aligned}
$$

Here, ϕ denotes the moment of the equation. The even moments are the balance equations and the odd ones are the fluxes. H_i are the non-parabolicity factors. For parabolic bands, $H_i = 1$. β is the kurtosis and denotes the deviation from the Maxwellian distribution function (see Figure 4). For the 2D and the 3D case the kurtosis is defined as:

$$
\beta = \frac{D}{D+2} n \frac{\langle \epsilon^2 \rangle}{\langle \epsilon \rangle^2}
$$

In Figure 3 we show the output characteristics of the 2D drift-diffusion, energy transport, and the six moments model of a SOI-MOSFET.

We introduce a 2D-nonparabolic-six-moments model for scaled devices. Due to the parameter modeling based on MC-tables, important effects like quantization as well as surface roughness scattering are inherently included.

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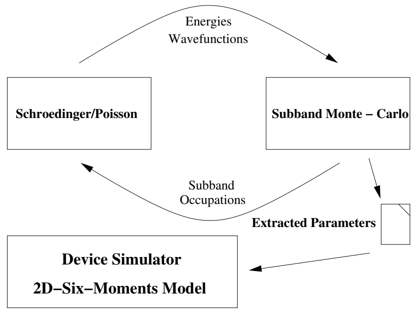

Figure 1: Transport parameters of a 2D-electron gas in an inversion layer are extracted selfconsistently and modeled through a whole device with a device simulator.

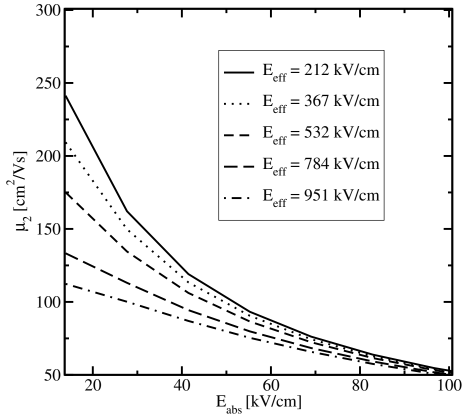

Figure 2: Extracted second-order mobility as a function of the driving field for different effective fields. The device simulator interpolates between these curves.

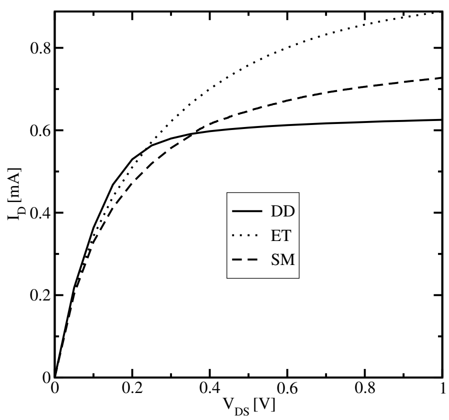

Figure 3: The output characteristic of a UTB SOI-Mosfet with a gate lenght of $40\,\mathrm{nm}$ calculated with the drift-diffusion model, the enery transport model, and the six moments model.

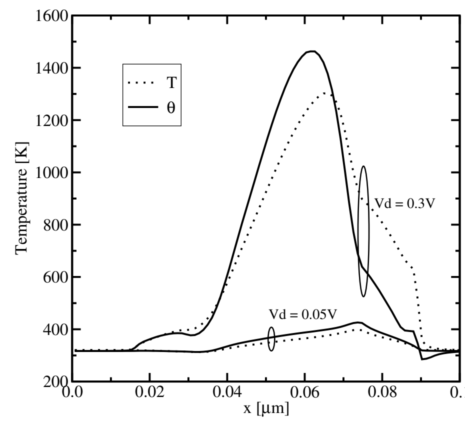

Figure 4: The second-order temperature $\theta = \beta T$ in comparison to the carrier temperature T. With increasing drain voltage, the deviation from the Maxwellian distribution ($\theta \approx T$, $\beta \approx 1$) increases.

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