An Improved Energy Transport Model Suitable for Simulation of Partially Depleted SOI MOSFETs

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Using the standard energy transport (ET) model for simulation of partially depleted SOI MOSFETs, an anomalous decrease of the drain current with increasing drain-source voltage has been observed (Fig. 1). The anomalous effect has been reproduced using the two device simulators MINIMOS-NT and DESSIS, and can be explained by an enhanced diffusion of channel hot carriers into the floating body [1]. It is believed that this decrease in current is an artifact because experimental data does not show this effect, nor can it be observed when using the drift-diffusion (DD) transport model. One exception is given in [2], where a weak decrease of the measured drain current of a p-MOS is reported.

In Monte Carlo (MC) simulations the spreading of hot carriers away from the surface of a MOSFET is much less pronounced than in ET simulations. Therefore, the assumptions underlying the ET model should be carefully reconsidered. While in the standard ET model an isotropic Maxwellian distribution is assumed to close the hierarchy of moments, in this work an equation set is derived from the Boltzmann equation permitting an anisotropic temperature and a non-Maxwellian distribution:

$$J_{n,l} = \mu_n \, \mathrm{k_B} \left(\nabla_l \big(n \, T_{ll} \big) + \frac{\mathrm{q}}{\mathrm{k_B}} \, E_l \, n \right)$$

$$S_{n,l} = -\frac{5}{2} \, \frac{\mathrm{k_B}}{\mathrm{q}} \, \mu_S \Big(\mathrm{k_B} \nabla_l \Big(n \, \beta_n \, T_{ll} \, \frac{3\,T_n + 2\,T_{ll}}{5} \Big) + \mathrm{q} \, E_l \, n \frac{3\,T_n + 2\,T_{ll}}{5} \Big)$$

T_{ll} denotes the temperature tensor component in direction $\vec{e}_l$, and β_n is the the normalized moment of fourth order. The solution variable is still the carrier temperature T_n, whereas the tensor components and β_n are modeled empirically as functions of T_n. A first empirical model of T_{ll} distinguishes between directions parallel and normal to the current density.

$$T_{ll} = T_{xx} \, \cos^2 \varphi + T_{yy} \, \sin^2 \varphi \;, \quad T_{xx} = \gamma_x(T_n) \, T_n \;, \quad T_{yy} = \gamma_y(T_n) \, T_n \;,$$

Off-diagonal components of the temperature are neglected. The anisotropy functions $\gamma_{x,y}(T_n)$ approach 1 for $T_n = T_L$ and an asymptotic value $\gamma_{0x,y}$ for large T_n. With this modification of the ET model it is possible to eliminate the spurious decrease in the output characteristic, but only by assuming a fairly large anisotropy of $\gamma_{0x} = 1.0$ and $\gamma_{0y} = 0.2$ (Fig. 2). MC simulations show that in most of the channel the high energy tail is less populated than that of a Maxwellian, which gives $\beta_n < 1$. A simple model $\beta_n(T_n)$ is assumed, giving 1 at T_L and an asymptotic value β_0 for large T_n. By combining this modified closure relation with the anisotropic temperature a much smaller anisotropy of $\gamma_{0y} = 0.6$ is sufficient (Fig. 3).

[1] M. Gritsch, H. Kosina, T. Grasser, and S. Selberherr, Solid-State Electron. **45**, 621 (2001).

[2] J. Egley *et al.*, in *Proc. Simulation of Semiconductor Processes and Devices* (IEEE, Seattle, Washington, USA, 2000), pp. 241–244.

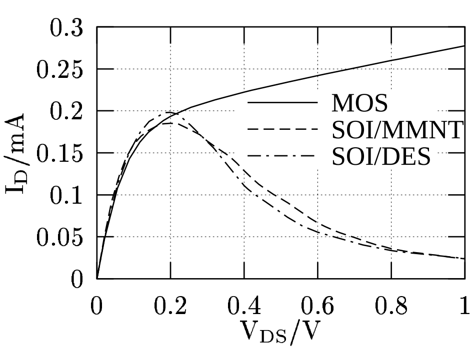

Figure 1: Output characteristics obtained by standard ET simulations using two different device simulators.

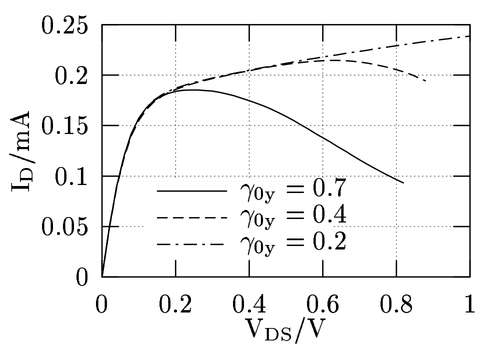

Figure 2: Output characteristics assuming anisotropic temperature. The closure relation is not modified ($\beta_0 = 1$).

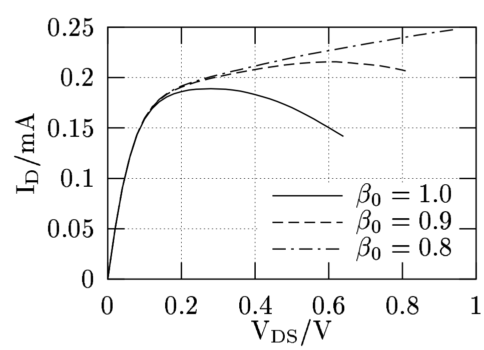

Figure 3: Output characteristics assuming anisotropic temperature ($\gamma_{0y} = 0.6$) and a modified closure relation.

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